

**ITRAC 3: 3rd Training Course on
Illicit Trafficking and Radiological Consequences with Nucleonica
Karlsruhe, 11-13 May 2011**

Introduction to the Gamma Spectrum Generator

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Department of Safeguards
Division of Technical Support*



Nucleonica - Gamma Spectrum Generator - Mozilla Firefox

Datei Bearbeiten Ansicht Chronik Lesezeichen Extras Hilfe

http://www.nucleonica.net/Application/Spectrum/Spectrum.aspx IAEA logo

Meistbesuchte Seiten Erste Schritte Aktuelle Nachrichten

Nucleonica - Gamma Spectrum Gene...

nucleonica ... web driven nuclear science

Applications Data Knowledge My Preferences Print Help New Browser

Eu152
1.6 h 9.28 h 13.53 y
Gamma Spectrum Generator
63 Europium
Actual chart: Karlsruhe

Getting started
Reference manual
Questions, remarks, suggestion
can be posted in the forum

Element: Mass:
Eu 152 Nuclide Mixtures Selector

Quantity: Reference point:
Bequerel 1000000 Measurement start

Measurement setup Calculation results Options

Measurement time: sec 1000 Start Start in background

Current configuration: NaI, L x D = 3 in x 3 in (default) Save as Delete

Dimensions in mm

Source Filter Crystal NaI Crystal diameter 76.2

250.0 Source to Detector distance 76.2 Crystal length Show more settings

Fertig

How to get to the GSG page:

1. Select Applications-
>Gamma Spectrum Generator
from the Nucleonica's main
menu

OR

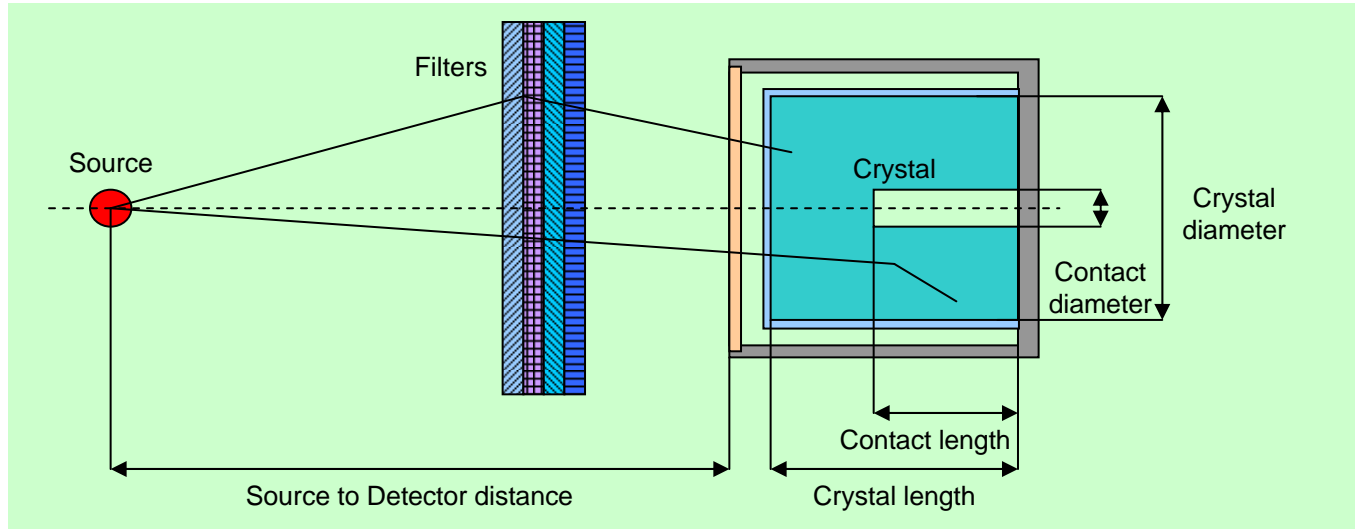
2. Go to the Nuclear Science
Applications Portal and select
Gamma Spectrum Generator
from the application list

nucleonica

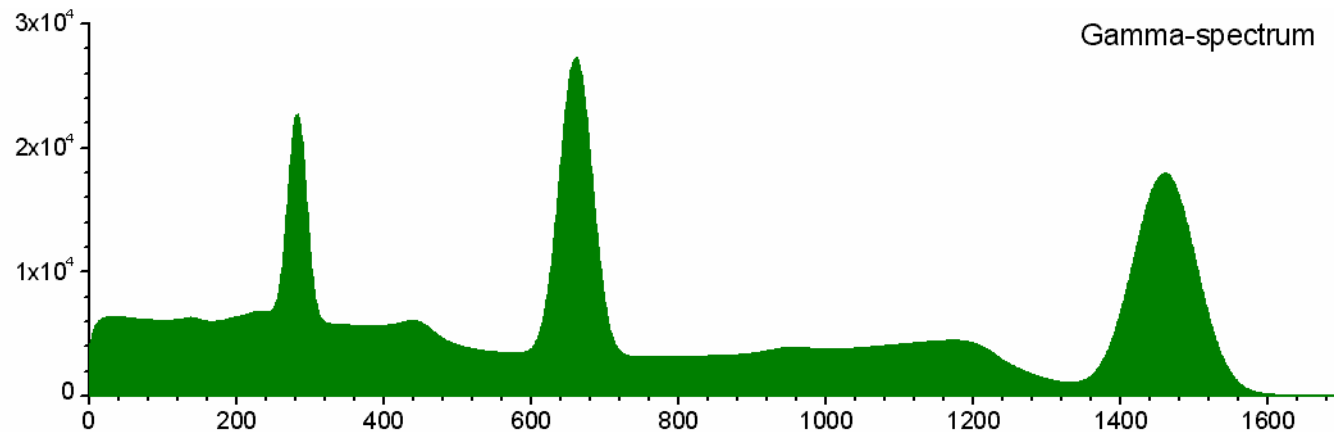
Outline

- **GSG in basic mode**
 - Modeling approach
 - Introduction to the GSG features
 - Experimental validation of the GSG
- **GSG-PRO**
 - Additional modeling features
 - Introduction to coupled eMC-GSG-PRO simulations
 - Examples of experimental validation
- **A simple application example**
- **Exercises**

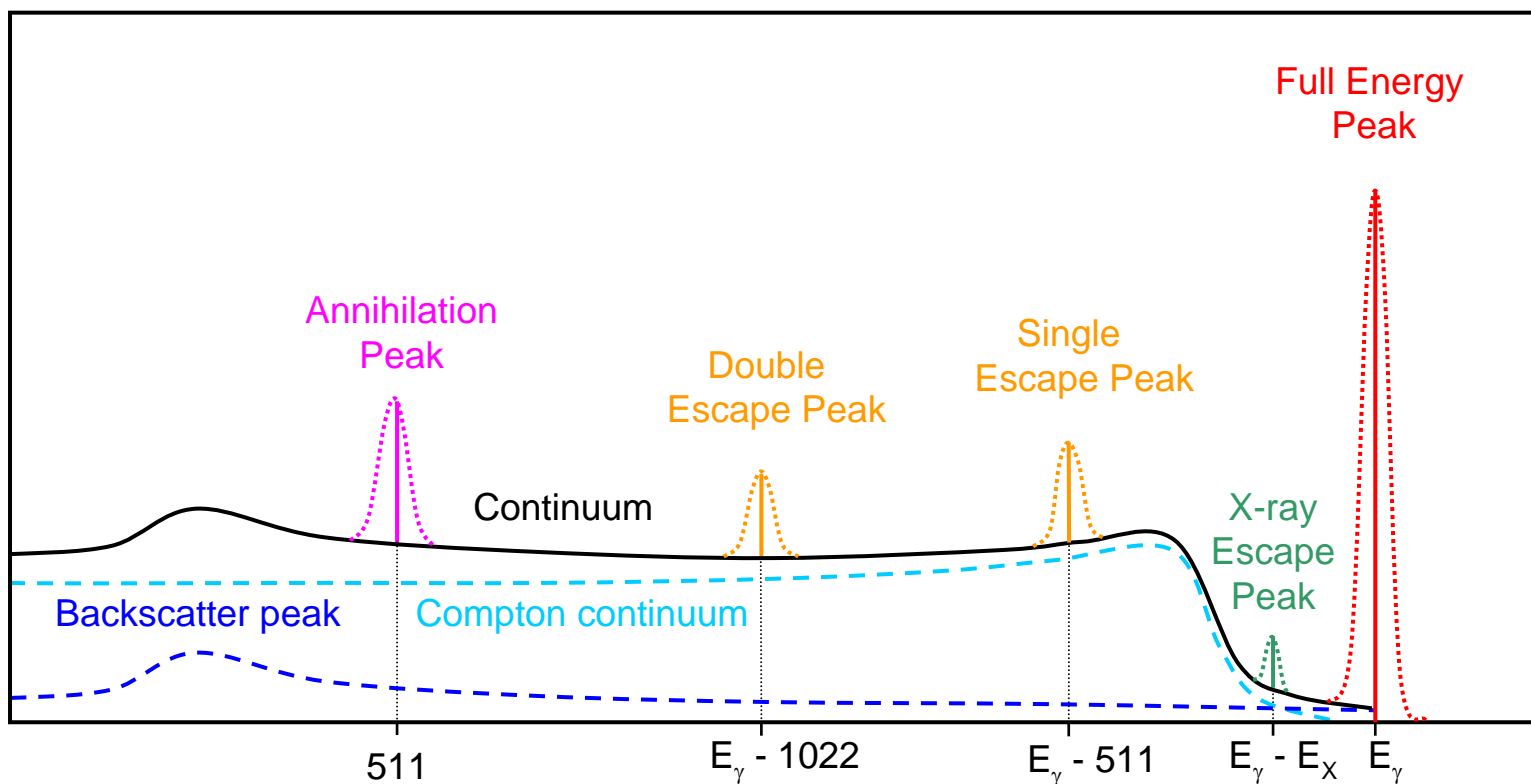
Measurement setup model implemented:



Spectrum modeling procedure:



- For spectrum modeling the GSG uses a comprehensive database of detector responses for gamma-ray energies from 10 keV to 10 MeV, which were obtained using extensive Monte Carlo simulations



- More details on the GSG simulation approach see in Nucleonica Wiki at http://www.nucleonica.net/wiki/index.php/Help:Gamma_Spectrum_Generator

Select an arbitrary individual nuclide or a pre-defined mixture of nuclides as a radiation source

Specify the quantity (activity, mass or number of atoms) of a nuclide or a mixture either

- at the spectrum measurement starting point of time, or
- at the moment of nuclide/mixture creation.

In the last case, the controls for specifying duration of a source "cooling" time interval become available.

Nucleonica - Gamma Spectrum Gene...

nucleonica ... web driven nuclear science

Applications Data Knowledge My Preferences Print Help New Browser

Getting started
Reference manual
Questions, remarks, suggestions
can be posted in the forum

Gamma Spectrum Generator
27 Cobalt
Actual chart: Karlsruhe

Element: Co Mass: 60 Nuclide Mixtures Selector

Quantity: Bequerel 1000000 Reference point: Nuclide creation "Cooling" time: sec 0

Measurement setup Calculation results Options

Measurement time: sec 1000 Start Start in background

Current configuration: <...Edit...> Save as Delete

Dimensions in mm

Source Filter Crystal

Source to Detector distance 250.0

Crystal length 76.2

Crystal diameter 76.2

Show more settings

Links to the quick start and detailed reference manuals, as well as to the GSG user's forum

Press "Start" button to start a simulation

- Choose a suitable γ -spectrometer from 6 pre-defined configurations, including HPGe and NaI detectors, or
- Select "Edit" to create a new spectrometer.

Tick the checkbox to get access to additional spectrometer settings

Configuring a new spectrometer:

Dimensions can be entered in "mm", "cm" or "inch" units

The configurable parameters include the source-to-detector distance, as well as dimensions and materials of the detector construction elements.

Dimensions in

Source

Filter

HPGe Crystal

59.0 Crystal diameter

10.0 Contact diameter

45.0 Contact length

70.0 Crystal length

250.0 Source to Detector distance

☒ Show more settings

Filter: Aluminum 0.2

Input window: Aluminum 0.5

Crystal packaging: Vacuum 3.0

Inactive layer / Reflector: Germanium 0.5

Number of channels in the spectrum accumulated: 8192

Channel-to-energy conversion factor, keV/channel: 0.3

Energy resolution (FWHM) in keV at 122 keV: 0.8

Energy resolution (FWHM) in keV at 1332 keV: 1.8

Add filter layer Remove filter layer

No.	Layer material	Thickness
1	Copper	1.0
2	Tin	0.5
3	Lead	0.1
4	Aluminum	0.2

The dimensions of a cylindrical contact at the rear side of the crystal (a construction feature of conventional coaxial HPGe detectors) can be specified


Up to 6 additional absorbing filters made of Al, Cu, Fe, Pb, Sn, or polyethylene can be placed between source and detector

Selecting calculation options:

Nucleonica - Gamma Spectrum Generator - Windows Internet Explorer

http://localhost:1652/WebSite1/Application/Spectrum.aspx#

Nucleonica - Gamma Spectrum Generator

 **Gamma Spectrum Generator**
Natural Uranium

Actual chart: Karlsruhe

Nuclide Mixtures:
Natural Uranium Nuclide Selector

Total activity:
Bequerel 2.557e+004

Reference point:
Measurement start

Measurement setup Calculation results Options

Gamma Spectrum Generator Settings:

- ☒ Display detector efficiency curves
- ☒ Consider decay transformations during cooling and counting time intervals
 - ☒ Include gamma-rays of daughter nuclides
 - 0.01 Decay Engine's accuracy factor
- ☒ Consider effects of backscatter radiation
 - 1.0 Backscatter peak normalisation factor

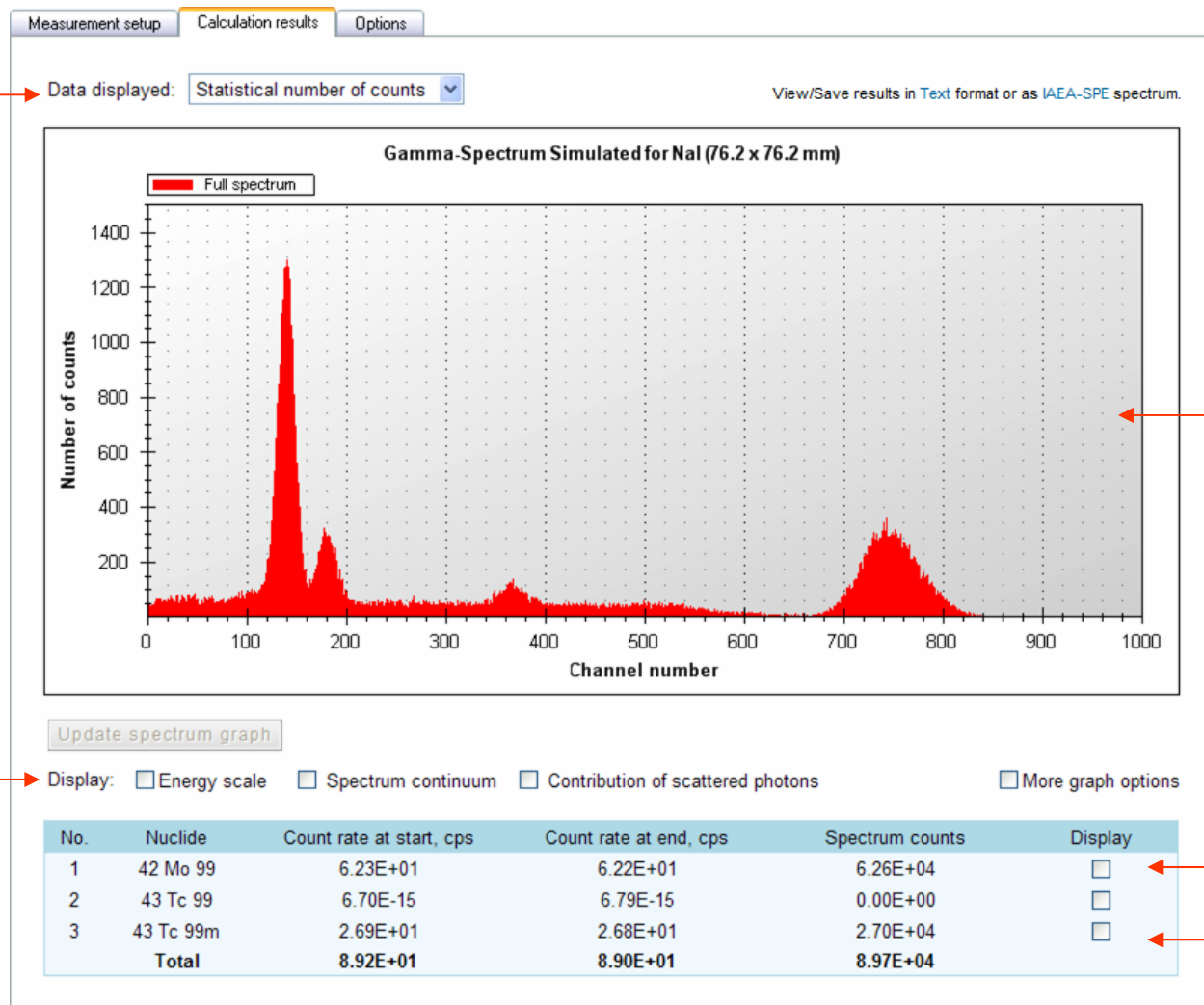
Efficiency Graph
can be activated
in the Calculation
Results output

The backscatter
peak simulation
can be switched
on/off, and its
contribution to
the spectrum can
be adjusted

Decay
calculations can
be enabled that
will allow
contributions
from decay
products, being
accumulated
during source
cooling and
spectrum
measurement
time intervals

Exploring calculation results:

Statistical number of counts
Count rate at start
Count rate at end
Theoretical number of counts
Statistical number of counts



Complete set of spectral information can be saved as a text file or as IAEA-SPE spectrum.

Right click within the graph area enables a context menu, from which one can print or download the spectrum graph

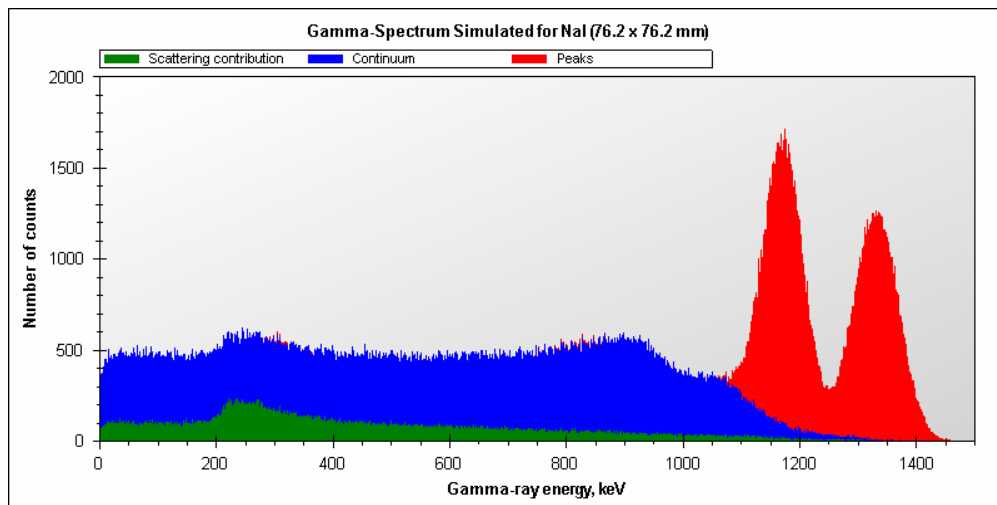
Additional options allow to customize appearance of the graph to meet one's needs and requirements

Switch between channel number and energy scale; show peak, continuum and backscatter peak contributions to the full spectrum

Display nuclide specific contributions to the full spectrum

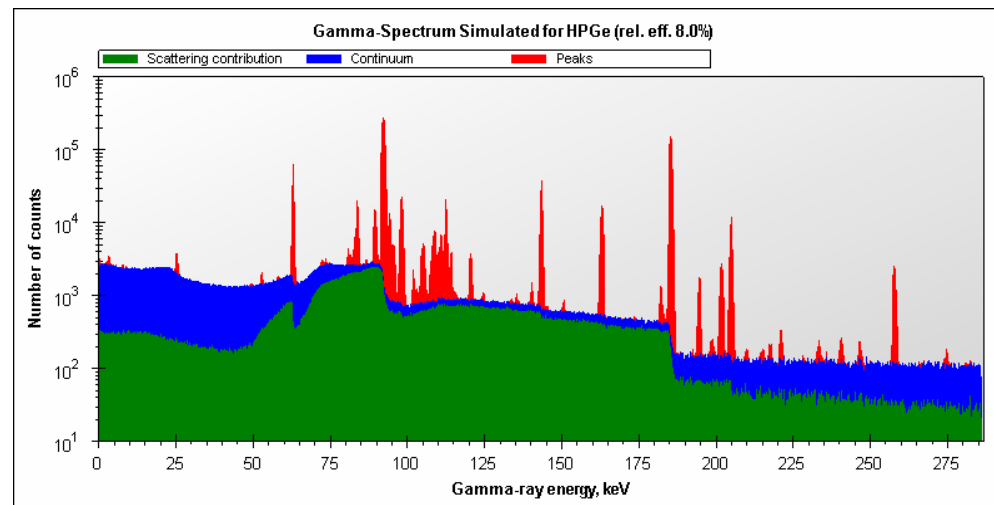
Displaying peak and continuum contributions:

100 kBq ^{60}Co



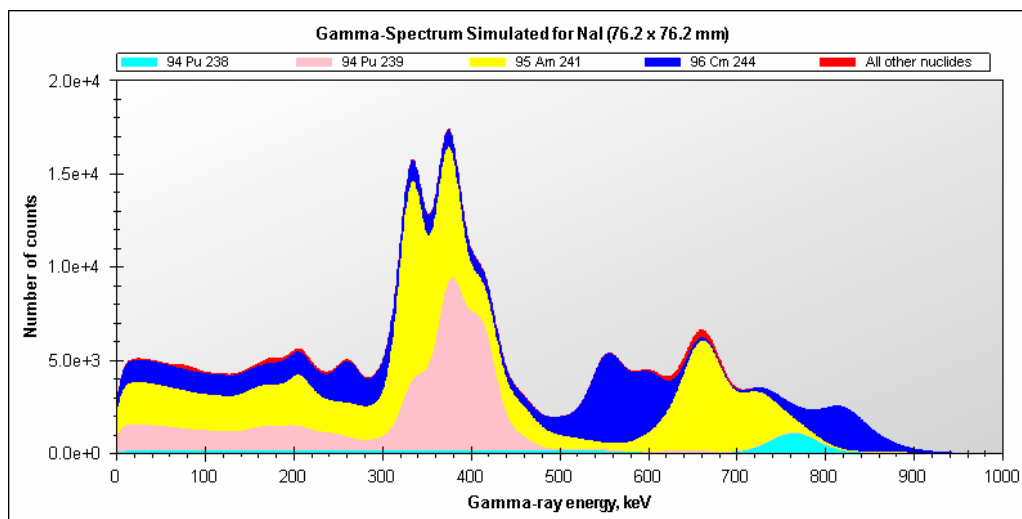
Detector - NaI ($\varnothing 3'' \times 3''$)
Source-to-detector distance - 25 cm
Measurement time - 1000 s

1 g Nat U (2 years after separation)

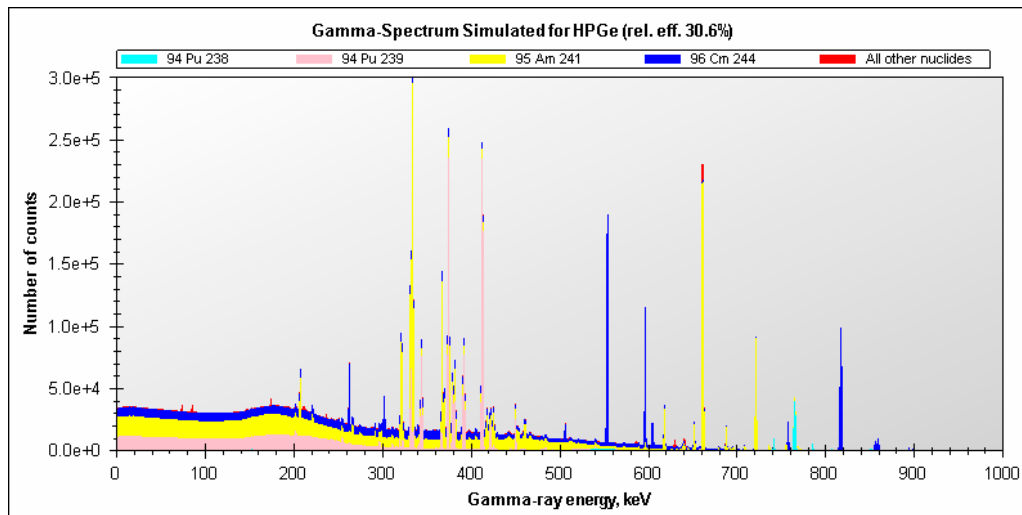


Detector – LEGe (20 mm x 2800 mm²)
Source-to-detector distance – 25 mm
Filter – 0.5 mm Sn
Measurement time - 10⁵ s

Displaying contributions of different nuclides:



Detector – NaI (Ø3"×3")
Source-to-detector distance – 25 cm
Filter – 5 mm Pb
Measurement time - 1000 s



Actinides extracted from 1 kg 6-year-aged PWR spent fuel. Activity - 5.25 TBq

Detector – BEGe (30% rel. eff.)
Source-to-detector distance – 25 cm
Filter – 5 mm Pb
Measurement time - 1000 s

Saving calculation results in Text / Excel formats:

Calculation Parameters

Microsoft Excel - GC-6020_Cs137_170mm_Spectrum.xls

	A	B	C	D	E
1	Nucleonica - GAMMA SPECTRUM GENERATOR Version 1.0.0.1				
2					
3	File content:	Calculation Results			
4	Created:	4/17/2008 3:21:29 PM (UTC)			
5					
6	SPECTROMETER:				
7	Configuration name	Noname			
8	Crystal type	HPGe			
9	Crystal length	52.00	mm		
10	Crystal diameter	72.20	mm		
11	Contact length	36.00	mm		
12	Contact diameter	10.00	mm		
13	Inactive layer	0.90	mm		
14	Crystal packaging	5.00	mm		
15	Detector input window	1.50	mm		
16	Number of additional filters	0.00	mm		
17	Filter No.1	0.00	mm		
18	Filter No.2	0			
19	Filter No.3	0			
20	Filter No.4	0			
21	Filter No.5	0			
22	Filter No.6	0			
23	FWHM at 122 keV	0			
24	FWHM at 1332.5 keV	0			
25	Number of channels	8			
26	Channel-to-Energy conversion	4			
27	Source-to-Detector distance	17			
28	Spectrum measurement time	67			
29					
30	SOURCE:				
31	Nuclide	56			
32	Quantity	70			
33	Reference point of time	N			
34	Source cooling interval	30	min		
35					
36	CALCULATION:				
37	Consider decay transformations	Yes			
38	Include gammas of daughter nuclides	Yes			
39	Decay engine's accuracy factor	0.01			
40	Consider backscatter radiation	Yes			
41	Backscatter peak normalization factor	2			
42					

Nuclide Specific Data

Microsoft Excel - GC-6020_Cs137_170mm_Spectrum.xls

	A	B	C	D	E	F	G	H	I
1	Nuclide	Ancestor	Activity, Bq		Number of	Count rate, cps		Number of counts	
2			at start	at end	decays	at start	at end	theor.	statist.
3	55 Cs 137	55 Cs 137	1.000E+00	1.000E+00	1.000E+00	5.652E-08	5.652E-08	5.652E-08	0.000E+00
4	56 Ba 137m	55 Cs 137	9.437E-01	9.395E-01	9.416E-01	7.177E-03	7.144E-03	7.160E-03	0.000E+00
5	TOTAL:		0.000E+00	0.000E+00	0.000E+00	7.177E-03	7.144E-03	7.160E-03	0.000E+00
6									

Gamma and X-ray Data

Microsoft Excel - GC-6020_Cs137_170mm_Spectrum.xls

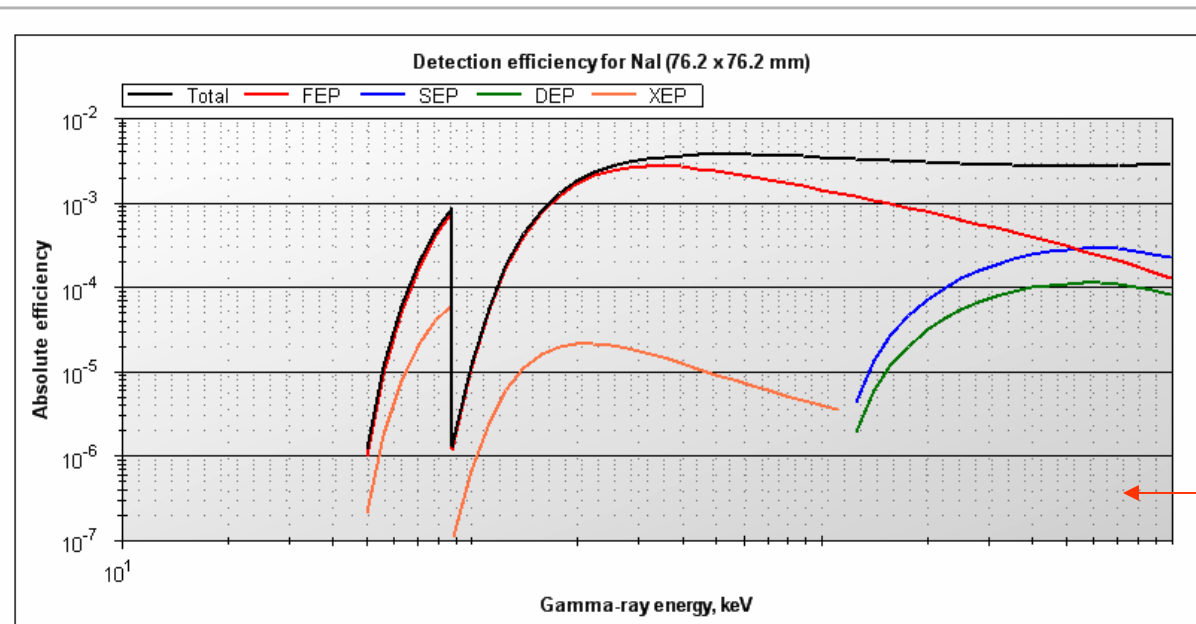
	A	B	C	D	E	F	G	H	I	J	K	L
	Energy, keV	X/G ray	Emission rate, 1/s		Photons emitted	Peak region counts		Detection efficiency		Ancestor's MDA(0), Bq		
			at start	at end		peak area	peak bkg	total	FEP			
350	G	5.800E-06	5.800E-06	5.800E-06	2.715E-08	4.094E-05	7.530E-03	4.681E-03	1.441E+08			
47	X	9.837E-03	9.793E-03	9.815E-03	0.000E+00	2.757E-05	0.000E+00	0.000E+00	NAN			
82	X	1.951E-02	1.943E-02	1.947E-02	5.198E-07	3.363E-05	2.775E-05	2.676E-05	9.635E+08			
19	X	3.600E-02	3.584E-02	3.592E-02	1.137E-06	3.301E-05	3.295E-05	3.171E-05	1.997E+08			
40	X	1.310E-02	1.304E-02	1.307E-02	2.193E-06	3.211E-05	1.727E-04	1.681E-04	5.304E+07			
66	G	8.500E-01	8.462E-01	8.481E-01	1.960E-03	2.144E-06	6.715E-03	2.311E-03	1.964E+03			

Gamma Spectrum

Microsoft Excel - GC-6020_Cs137_170mm_Spectrum.xls

	A	B	C	D	E	F	G	H	I	J	K
1	Energy, keV	Count rate at start, cps		Count rate at end, cps	Theoretical number of counts						
2		Continuum	Scattered	Total	Continuum	Scattered	Total	Continuum	Scattered	Total	
3	0.20	2.637E-06	8.042E-07	2.650E-06	2.625E-06	8.006E-07	2.638E-06	2.631E-06	8.024E-07	2.644E-06	
4	0.60	3.185E-06	9.725E-07	3.218E-06	3.171E-06	9.681E-07	3.204E-06	3.178E-06	9.703E-07	3.211E-06	
5	1.00	3.335E-06	1.019E-06	3.376E-06	3.320E-06	1.015E-06	3.360E-06	3.327E-06	1.017E-06	3.368E-06	
6	1.40	3.381E-06	1.035E-06	3.394E-06	3.366E-06	1.030E-06	3.379E-06	3.373E-06	1.032E-06	3.387E-06	
7	1.80	3.400E-06	1.042E-06	3.401E-06	3.385E-06	1.037E-06	3.385E-06	3.392E-06	1.039E-06	3.393E-06	
8	2.20	3.411E-06	1.046E-06	3.411E-06	3.396E-06	1.042E-06	3.396E-06	3.404E-06	1.044E-06	3.404E-06	
9	2.60	3.421E-06	1.050E-06	3.421E-06	3.405E-06	1.046E-06	3.405E-06	3.413E-06	1.048E-06	3.413E-06	

Plotting detection efficiencies:



Update efficiency graph

Efficiencies displayed: ☒ Full Energy Peak (FEP) ☒ Single Escape Peak (SEP) ☒ Total
☒ X-ray Escape Peak (XEP) ☒ Double Escape Peak (DEP)

☒ More graph options

X-axis settings:		Y-axis settings:	
Scale <input checked="" type="checkbox"/> Auto <input checked="" type="checkbox"/> Log Minimum: 10 Maximum: 10000	Tick steps <input checked="" type="checkbox"/> Auto Major step: 1000 Substeps No: 5	Scale <input checked="" type="checkbox"/> Auto <input checked="" type="checkbox"/> Log Minimum: 0 Maximum: 1.00	Tick steps <input checked="" type="checkbox"/> Auto Major step: 0.01 Substeps No: 5
Grid lines <input checked="" type="checkbox"/> Major <input checked="" type="checkbox"/> Minor	Ticks <input checked="" type="checkbox"/> In <input checked="" type="checkbox"/> Out <input checked="" type="checkbox"/> Labels	Grid lines <input checked="" type="checkbox"/> Major <input checked="" type="checkbox"/> Minor	Ticks <input checked="" type="checkbox"/> In <input checked="" type="checkbox"/> Out <input checked="" type="checkbox"/> Labels

Select efficiency data to be displayed on the graph

Right click within the graph area enables a context menu, from which one can print or download the efficiency graph

Additional options allow to tailor the efficiency graph to one's needs and requirements

Experimental validation with 60% HPGe coaxial detector (INR, Kiev)

Detector: coaxial HPGe (Canberra)

- Relative efficiency: 61.8%
- Crystal dimensions: $\varnothing 74 \text{ mm} \times 53 \text{ mm}$
- Rear contact: $\varnothing 10 \text{ mm} \times 36 \text{ mm}$
- Inactive Ge: 0.7 mm
- Crystal end cap: 1.5 mm Al
- End cap to crystal gap: 5 mm
- FWHM: 1.75 keV at 1.33 MeV

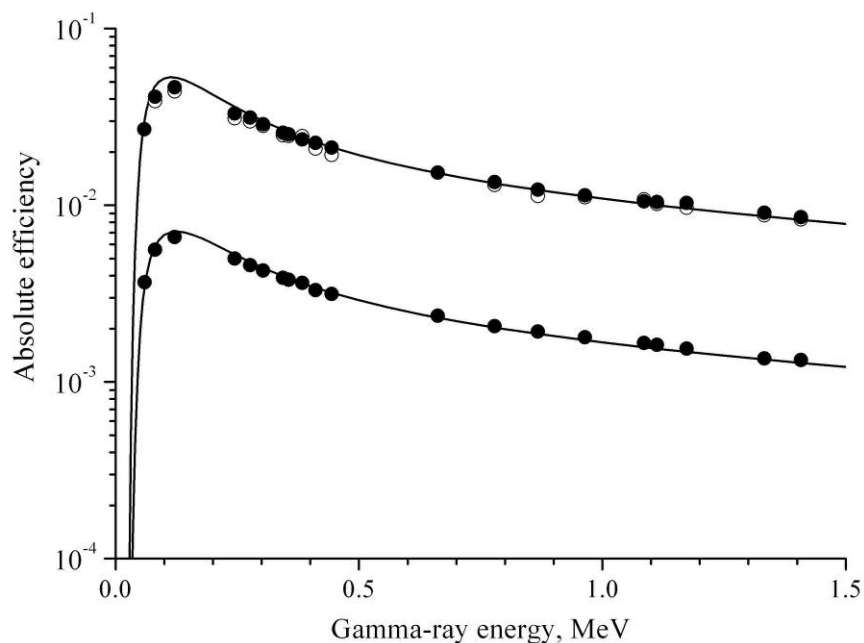
Sources: Thin Spectroscopic Reference Gamma-Sources (SOSGI)

- ^{137}Cs , ^{60}Co , ^{152}Eu

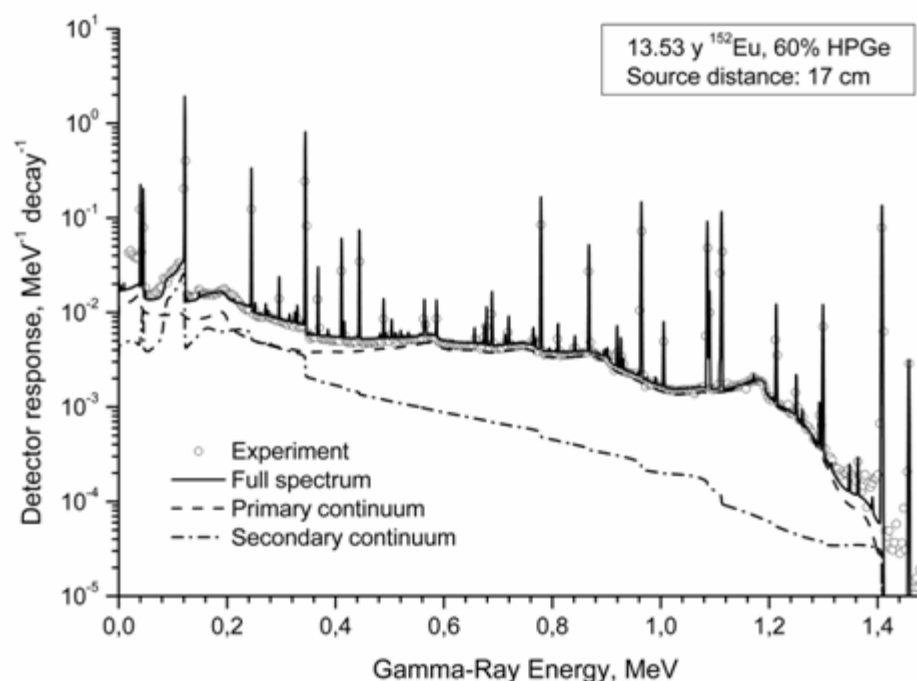
Measurement conditions: Center of experimental room



Results of the experimental validation with 60% HPGe coaxial detector



Full Energy Peak efficiency as a function of the photon energy: circles – experimental values, curve – calculated. Two sets of data refer to the source location at 5 cm and 17 cm distances from the detector end cap.



Calculated (curve) and experimental (circles) detector responses for ¹⁵²Eu source at 17 cm distance from the detector end cap.

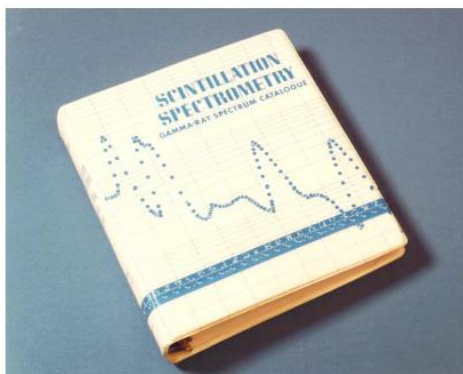
REVISED EDITION OF REPORT IDO - 16880 - 1
ORIGINAL ISSUED: AUGUST 1964
REV. ELECTRONIC UPDATE: FEBRUARY 1997

SCINTILLATION SPECTROMETRY GAMMA-RAY SPECTRUM CATALOGUE

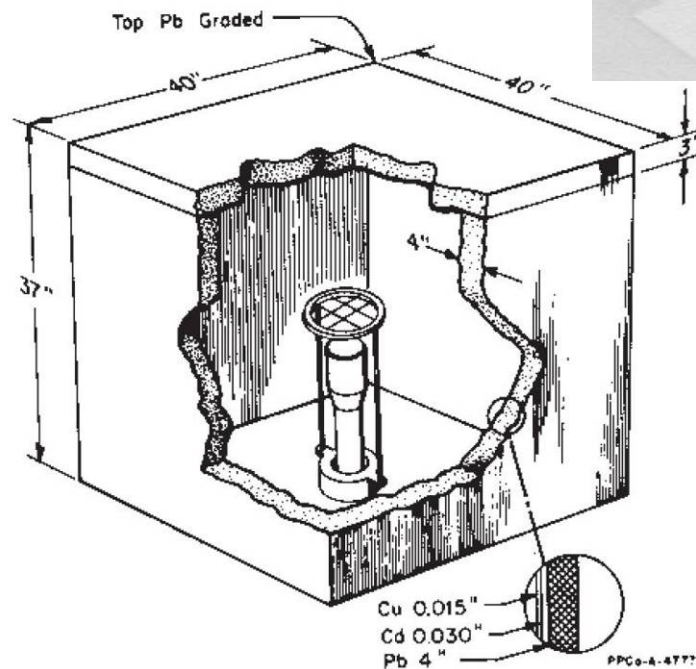
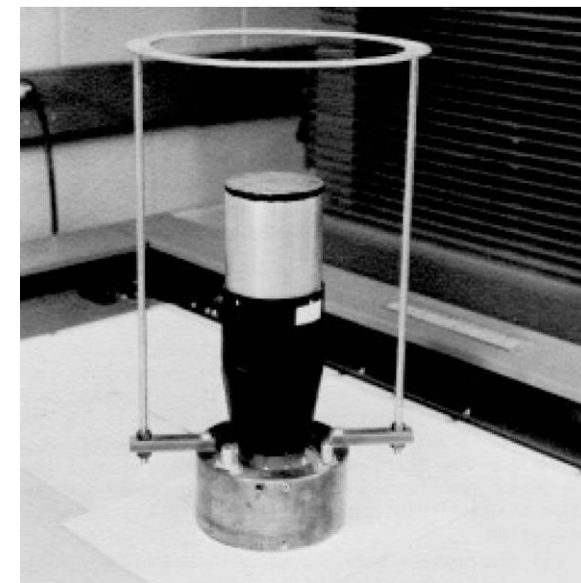
NEW VERSION OF 2ND EDITION
COMPILATION OF GAMMA-RAY SPECTRA
AND RELATED NUCLEAR DECAY DATA
VOLUME 1 OF 2

BY

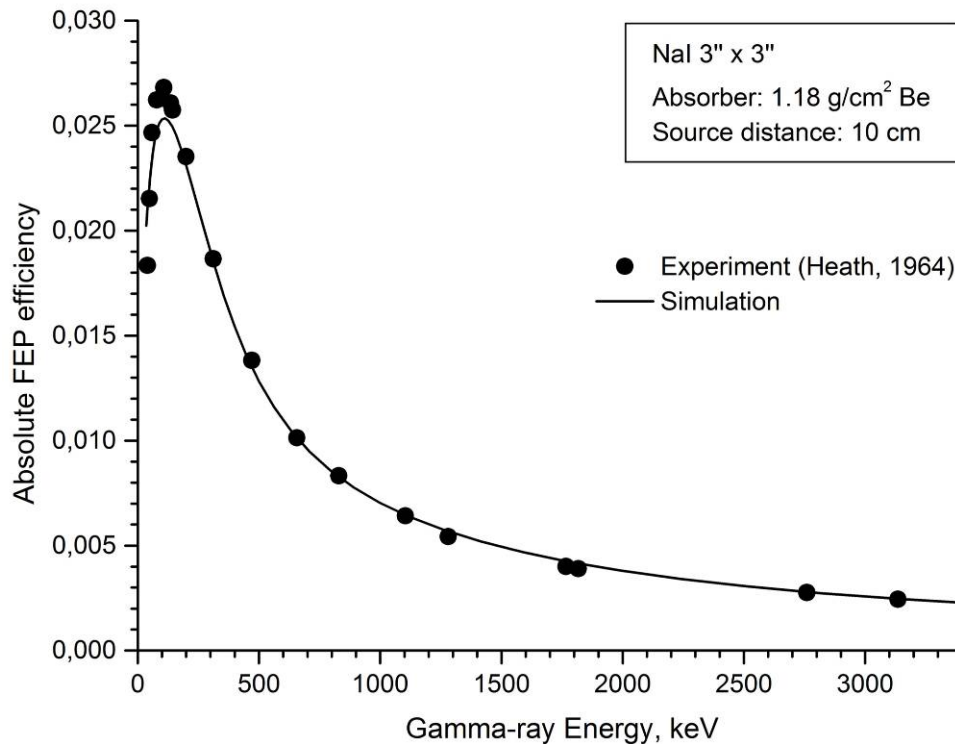
R. L. HEATH



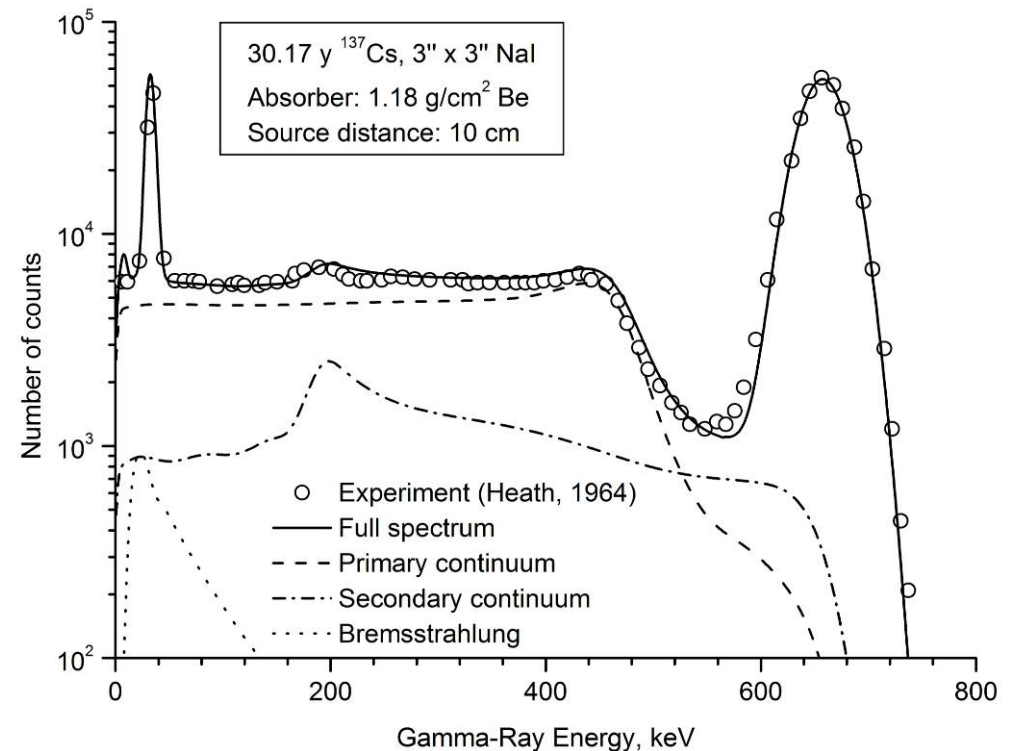
Detector:
3" × 3" NaI scintillation
detector



Results of the experimental validation with 3" × 3" NaI scintillation detector

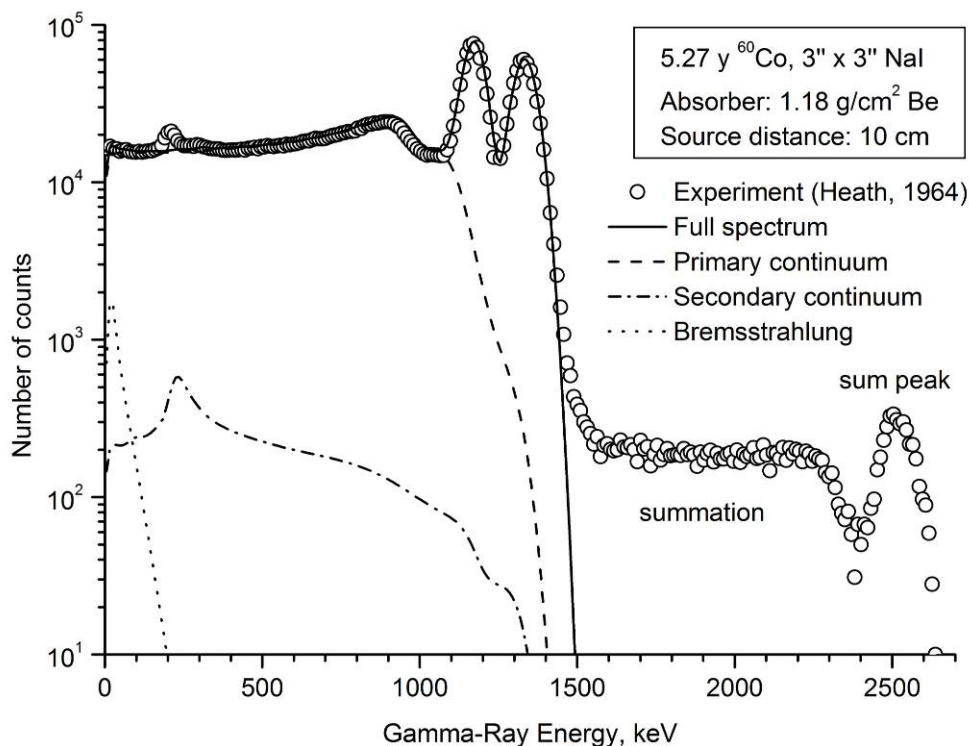


The simulated vs. experimental *FEP* efficiencies for a NaI 3" × 3" detector.

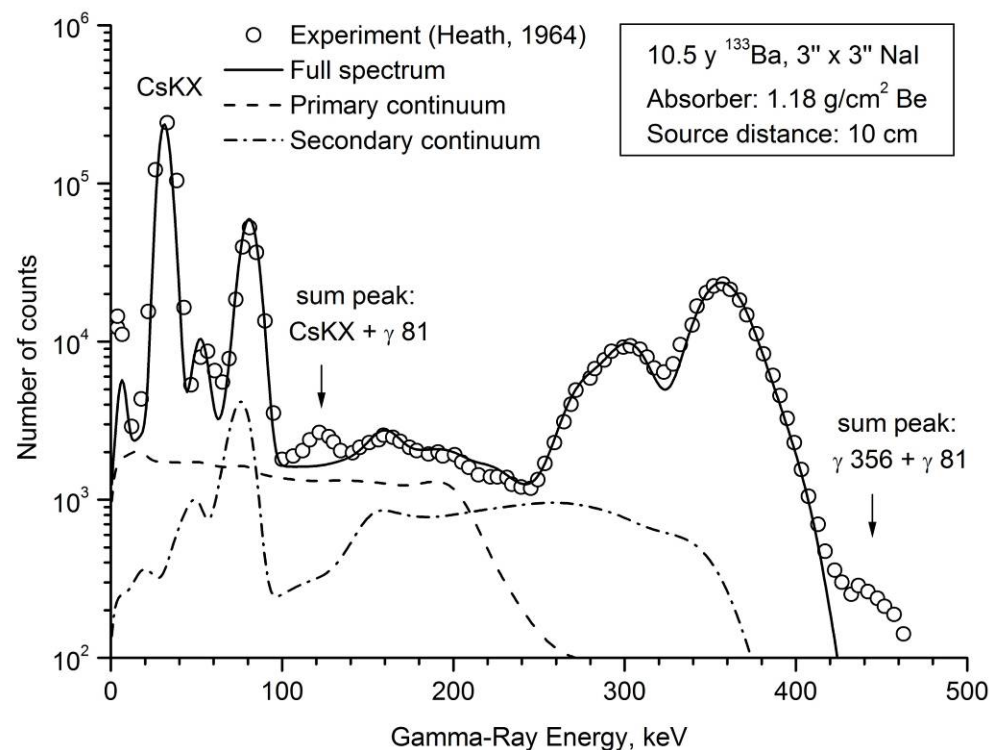


The experimental and simulated spectra for ¹³⁷Cs and a NaI 3" × 3" detector .

Results of the experimental validation with 3" × 3" NaI scintillation detector

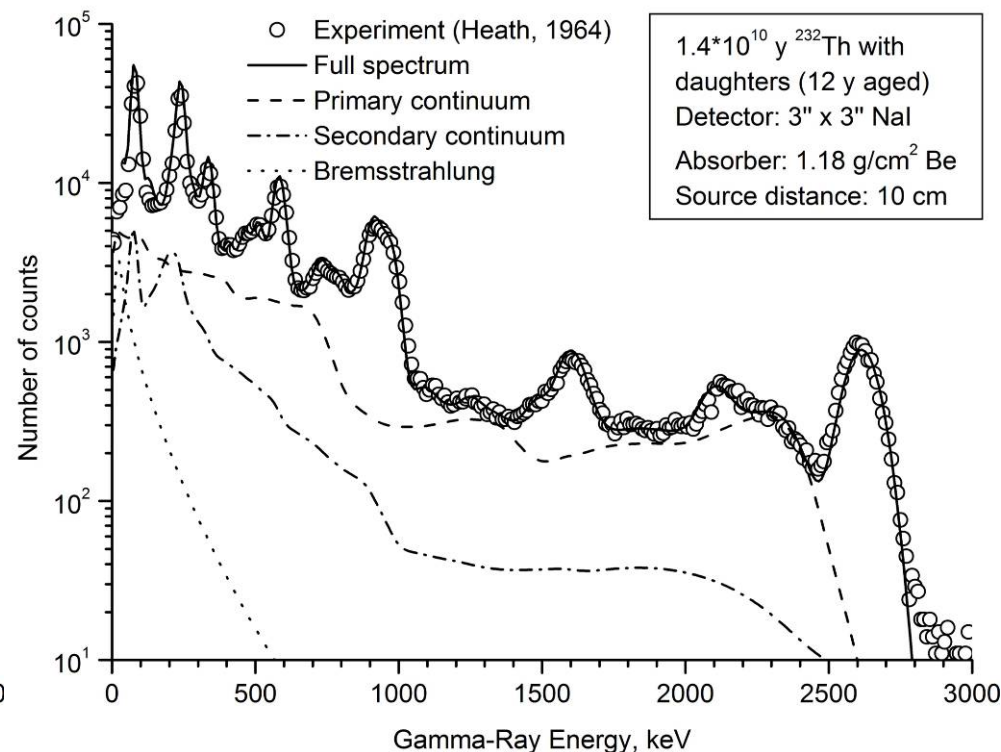
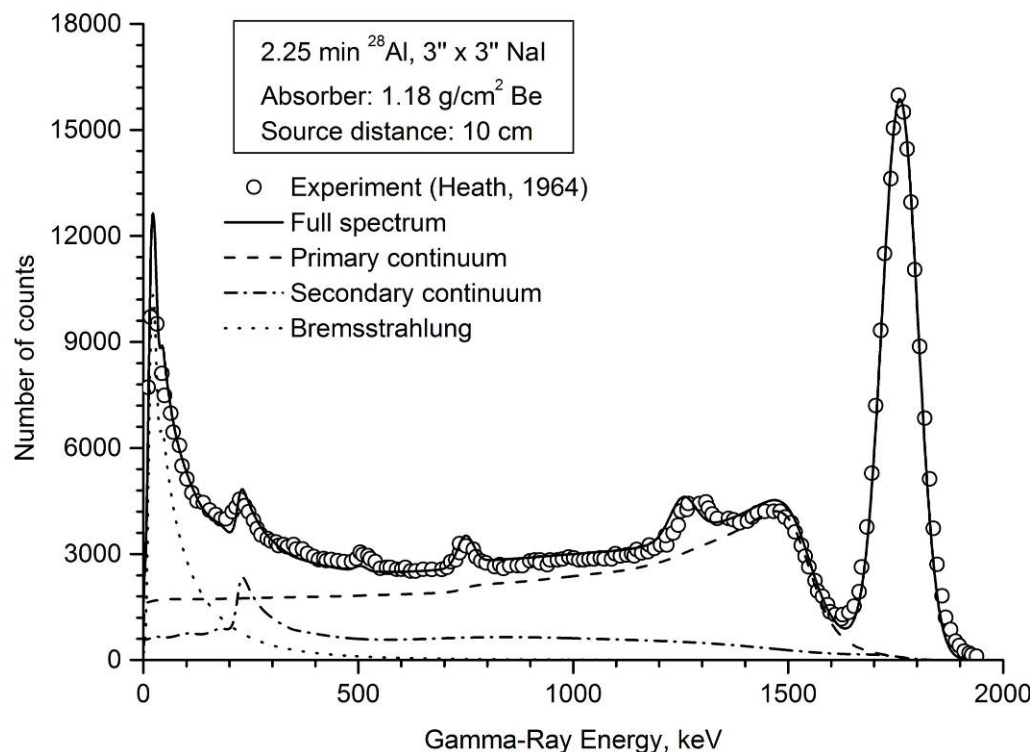


The experimental and simulated spectra for ^{60}Co and a NaI 3" × 3" detector.



The experimental and simulated spectra for ^{133}Ba and a NaI 3" × 3" detector.

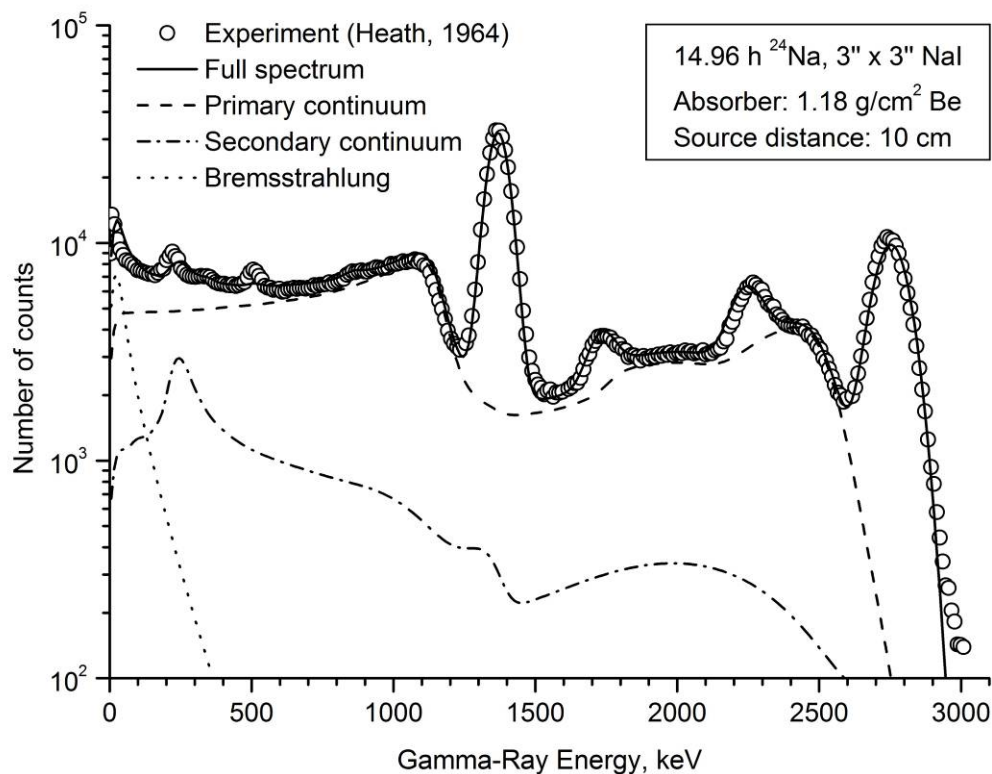
Results of the experimental validation with 3" × 3" NaI scintillation detector



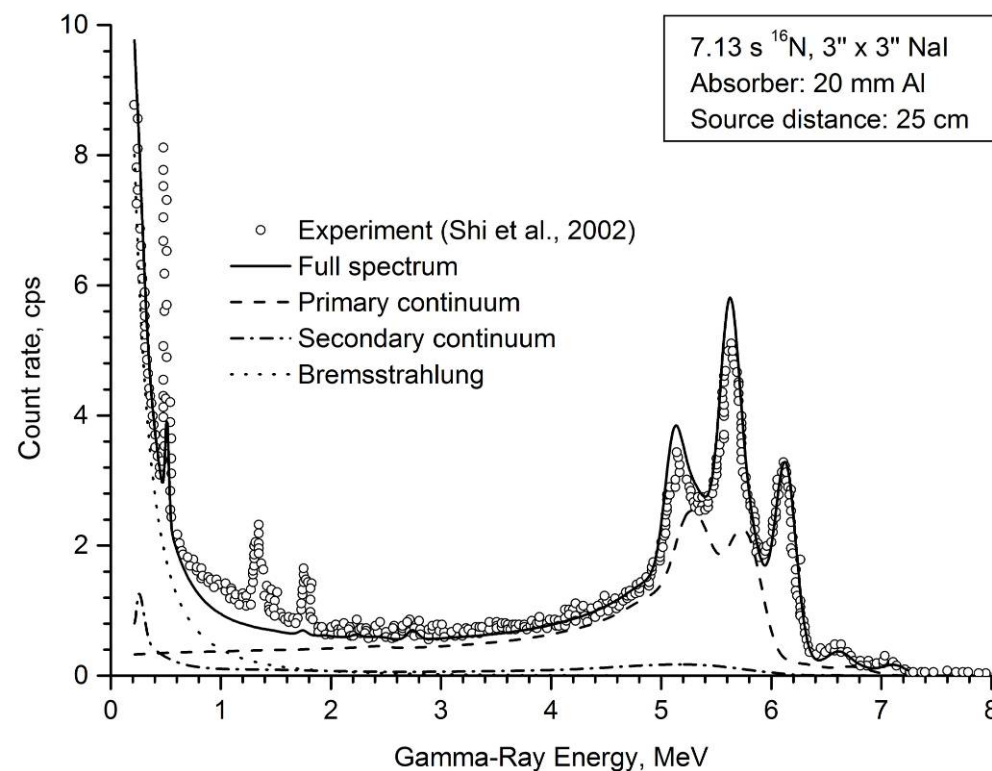
The experimental and simulated spectra for ^{28}Al and a NaI 3" × 3" detector .

The experimental and simulated spectra for a 12 year old ^{232}Th source and a NaI 3" × 3" detector.

Results of the experimental validation with 3" × 3" NaI scintillation detector



The experimental and simulated spectra for ^{24}Na and a NaI 3" × 3" detector.



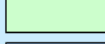



The experimental and simulated spectra for ^{16}N and a NaI 3" × 3" detector.

1. Modeling of a contribution from naturally occurring radionuclides (natural gamma radiation background)

Additional interface features:

Additional measurement setup properties:

	Absorbing filter layers:	Aluminum	1.0	Add	Del	No.	Layer material	Thickness
	Input window:	Aluminum	0.5					
	Crystal packaging:	Foam Plastic	0.0					
	Inactive layer / Reflector:	Aluminium oxide	0.5					

ADC and energy resolution parameters:

2048	Number of spectrum channels	18.0	Energy resolution (FWHM) at 122 keV, keV
1.0	Channel-to-energy conversion factor, keV/channel	90.0	Energy resolution (FWHM) at 1332 keV, keV

Background gamma-ray peak and continuum intensities, cps:

0.013	Count rate in 185.7 keV peak of U-235	0.0003	Count rate in 661.6 keV peak of Cs-137
0.012	Count rate in 238.6 keV peak of Pb-212 (Th-232)	0.00015	Count rate in 1332.5 keV peak of Co-60
0.035	Count rate in annihilation 511.0 keV peak	0.02	Count rate in 1460.8 keV peak of K-40
0.006	Count rate in 609.3 keV peak of Bi-214 (U-238)	3	Continuum count rate (0 - 3 MeV)

Measurement setup Calculation results Options

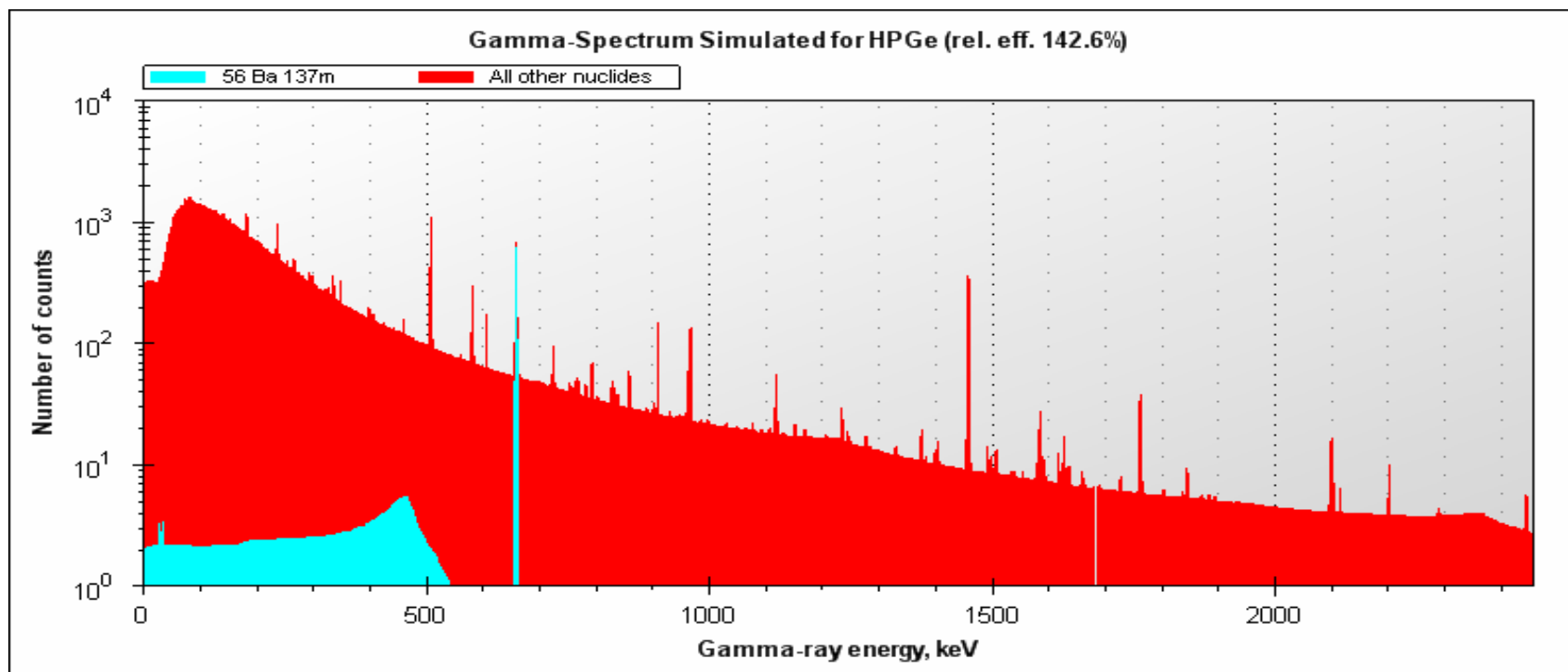
Gamma Spectrum Generator Settings:

- ☐ Display detector efficiency curves
- ☐ Consider decay transformations during cooling and counting time intervals
- ☐ Consider effects of backscatter radiation
- ☐ Consider bremsstrahlung photon creation
- ☒ Simulate natural gamma-ray background

A respective option has to be selected on „Options“ tab to enable the background simulation

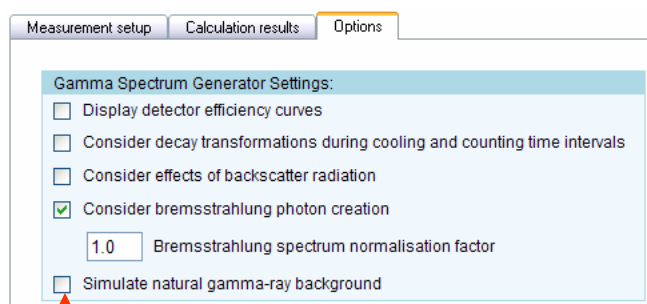
Example: low-activity / low-background measurements

Inclusion of the background gammas results in a more realistic spectrum shape and MDA values, especially in low-activity measurements

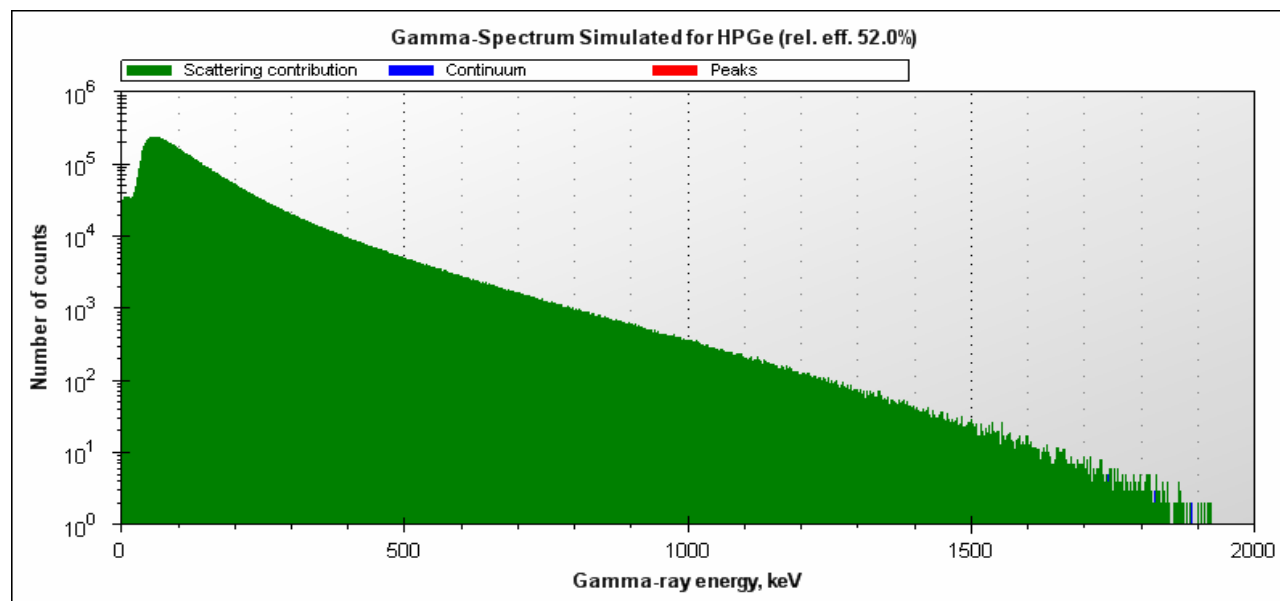


- A spectrum simulated for a 10 Bq ^{137}Cs source at the 10 mm distance from a 150% HPGe detector with natural background contribution included

2. Bremsstrahlung modeling option is available for beta-emitting nuclides:

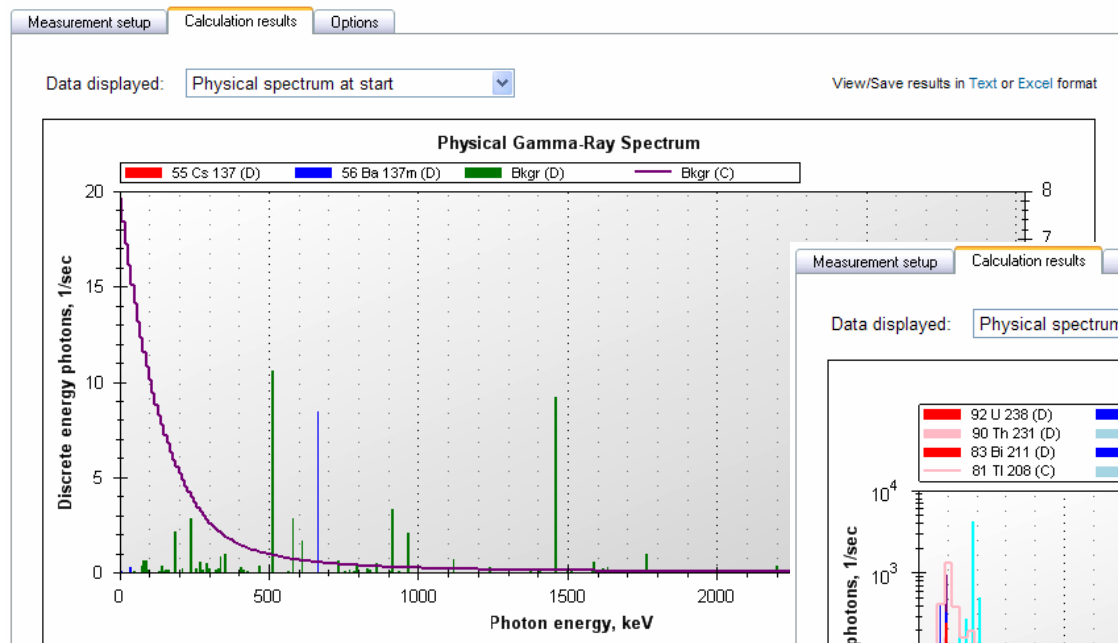


A respective option must be selected on „Options“ tab to enable the bremsstrahlung simulation.



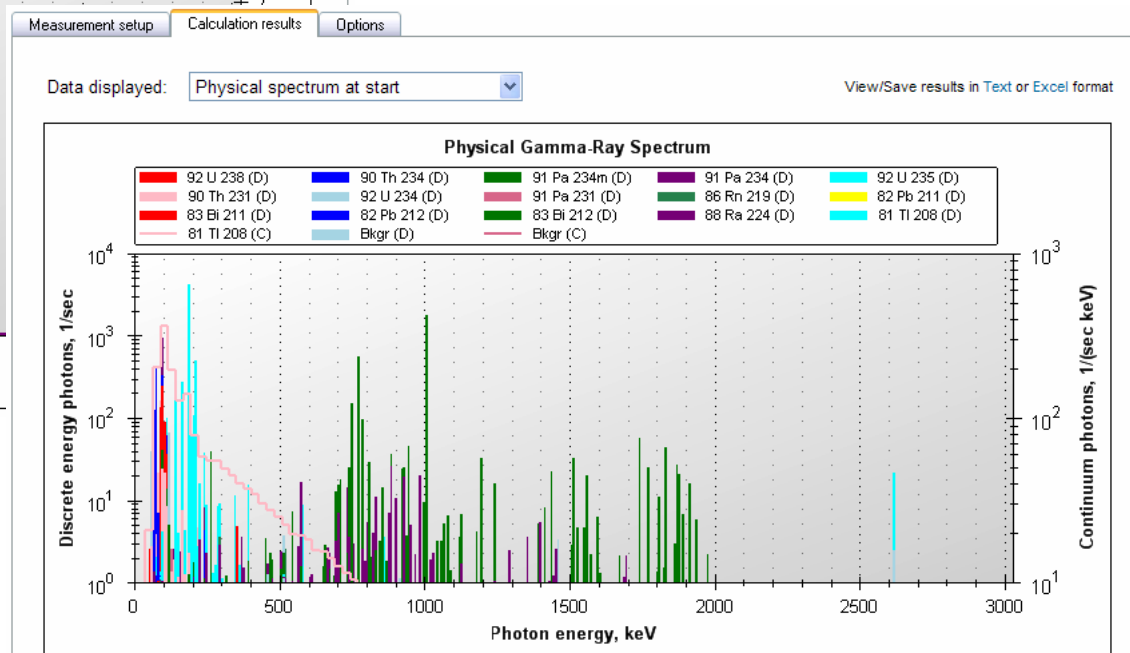
- A gamma-spectrum simulated for the 10 MBq ^{90}Sr - ^{90}Y source and a 50% HPGe coaxial detector

3. Physical photon spectrum visualization

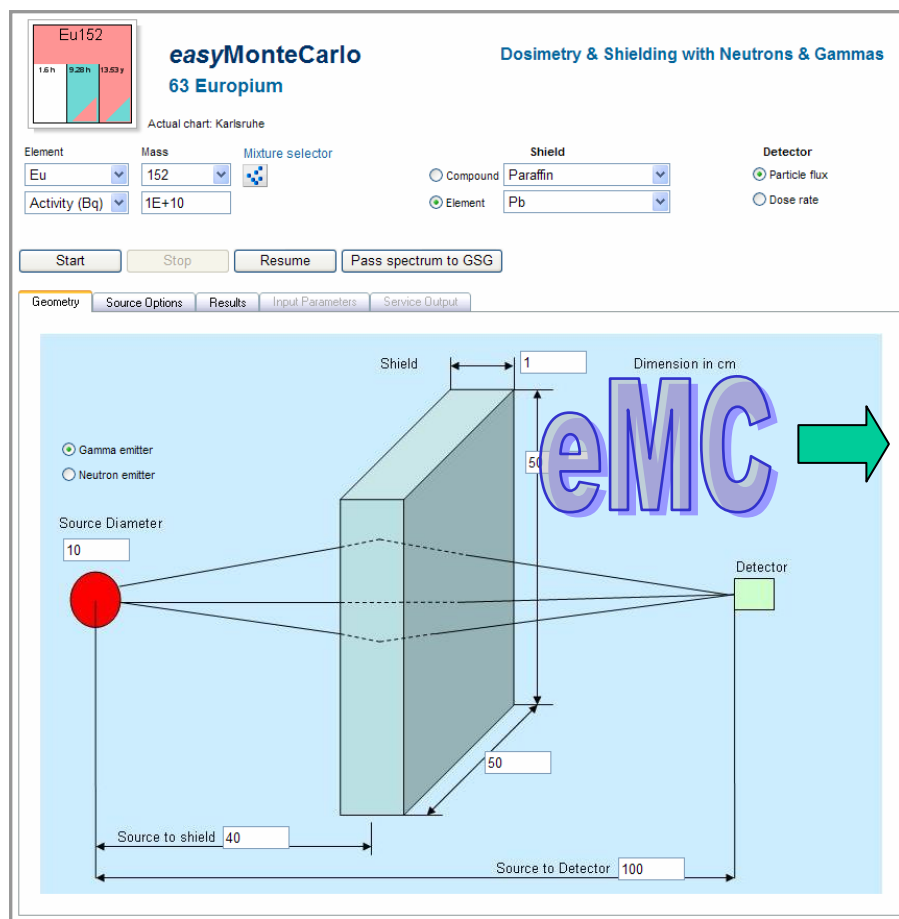


¹³⁷Cs source and natural background photons

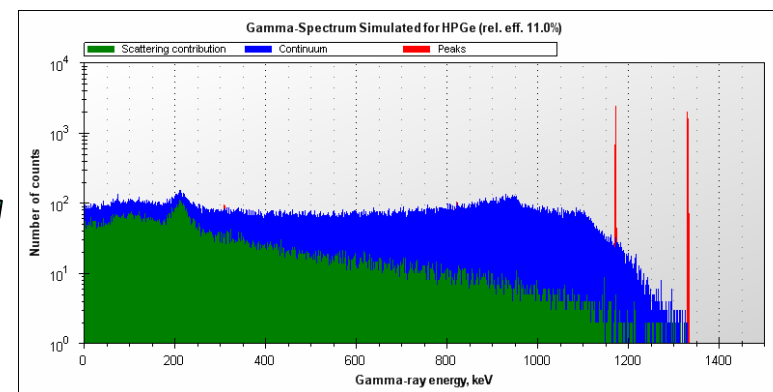
4.46% Uranium source and natural background photons



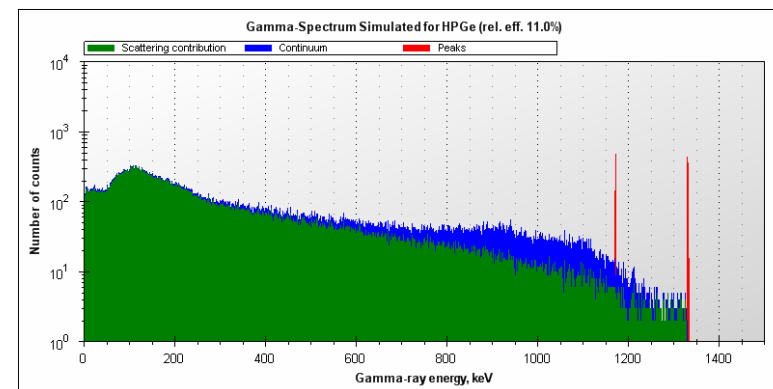
4. Modeling spectra from voluminous and heavily shielded sources using a coupled eMC (easy Monte Carlo) – GSG-PRO simulation approach:



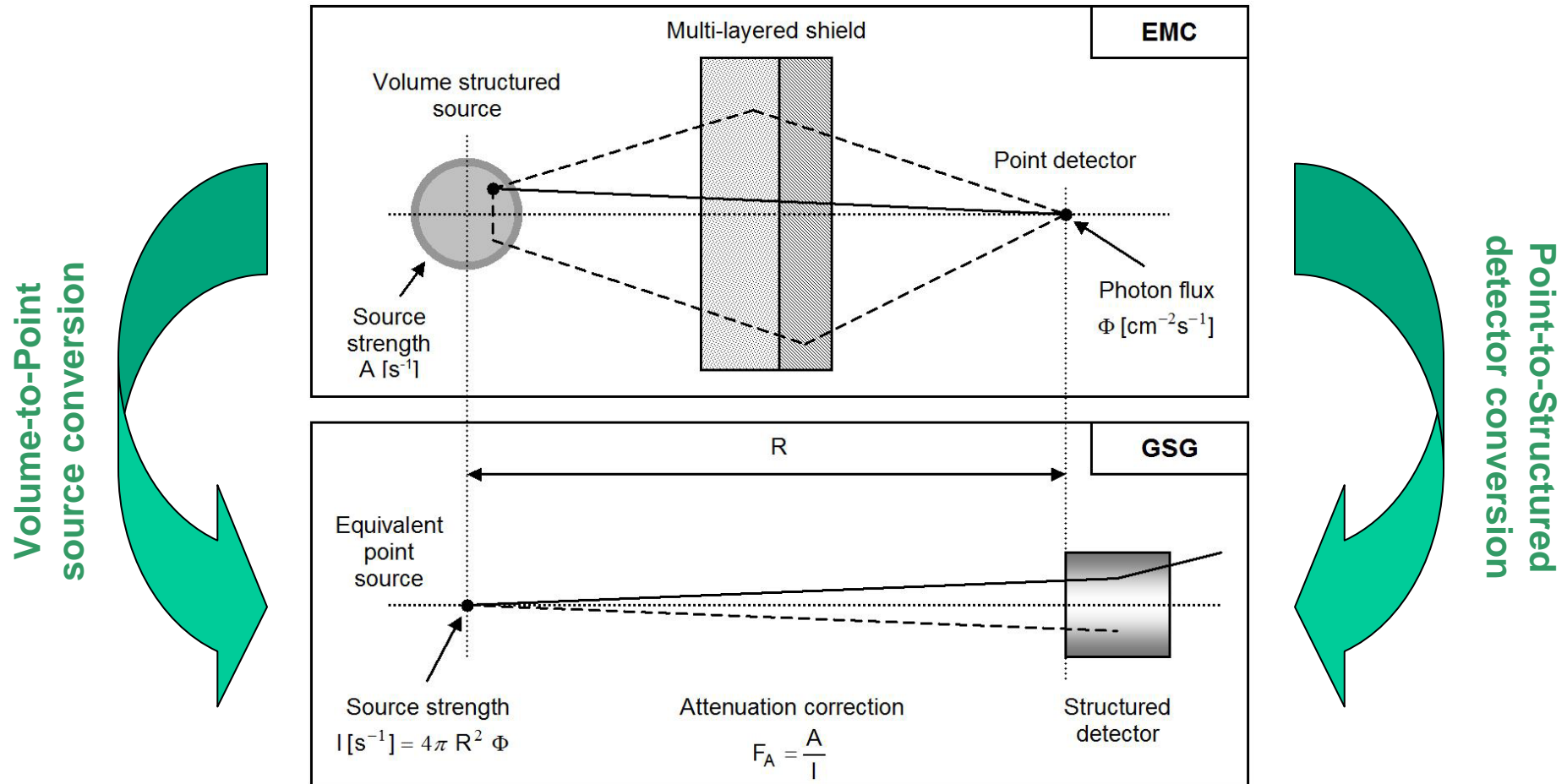
Unshielded ^{60}Co :

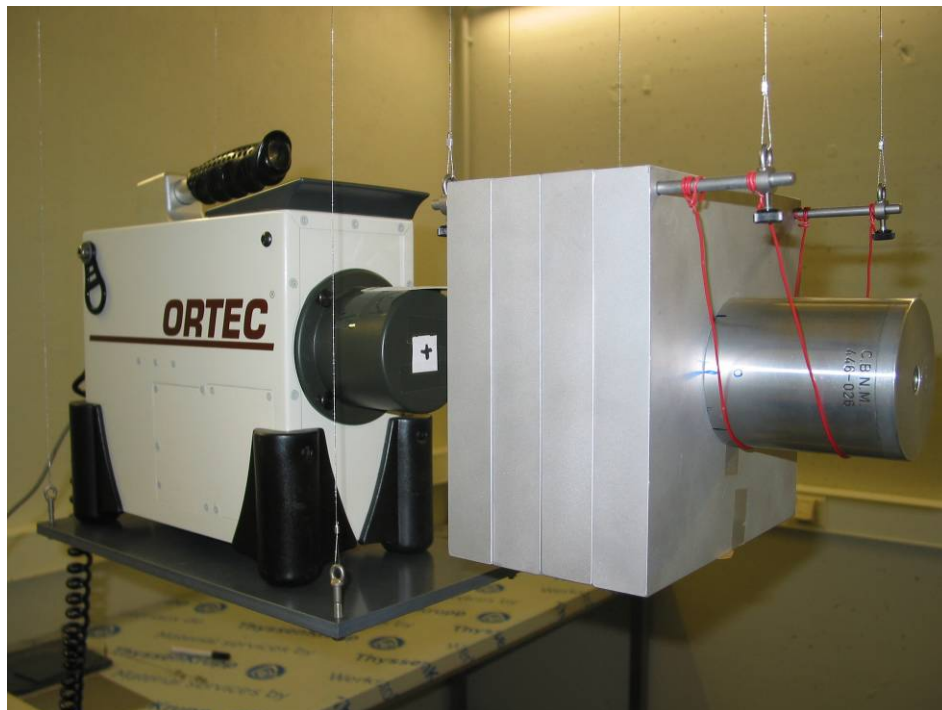


^{60}Co behind 12 cm Al shield:



Coupled eMC / GSG-PRO calculations for voluminous & shielded sources:



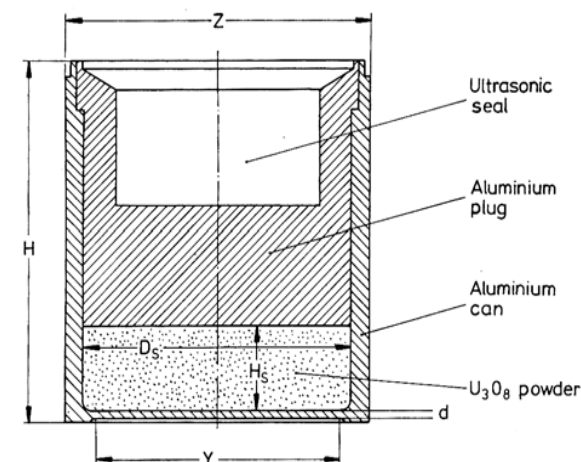


Experimental room: $L \times W \times H = 3.3 \times 3.8 \times 3.5 \text{ m}^3$.
 Shields ($20 \times 20 \text{ cm}^2$): Pb (2 cm) and Al (3 cm, 12 cm).
 Detector: 10% Ortec Detective, HPGe $\varnothing 50 \times 30 \text{ mm}$.
 Shield to detector: 10 cm.
 Source to shield: 0 cm.
 Unshielded source: at 10 cm distance.

CBNM-446 Uranium:

Separation date: 1979
 U_3O_8 , 200 g, 3.3 g/cm^3
 Capsule: $\varnothing 8 \times 9 \text{ cm}$
 Sample: $\varnothing 7 \times 1.58 \text{ cm}$
 Al window: 0.2 cm

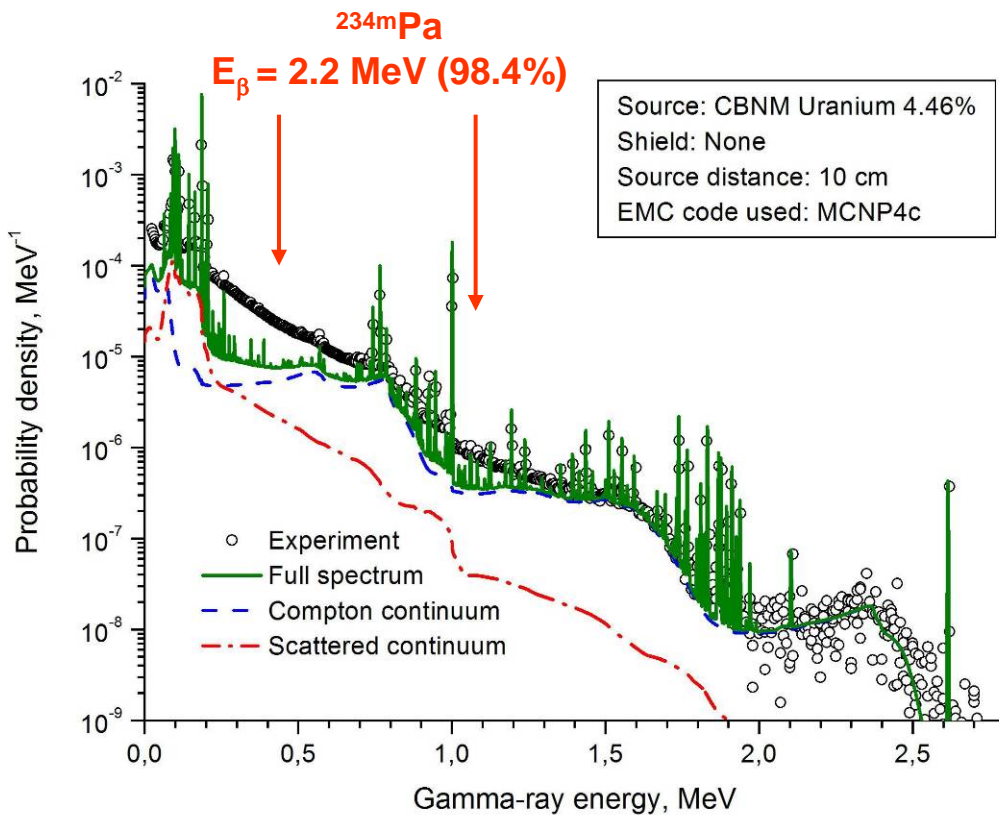
^{232}U – 4.1 ppt
 ^{234}U – 0.0359 wt %
 ^{235}U – 4.4623 wt %
 ^{236}U – 0.0068 wt %
 ^{238}U – 95.495 wt %



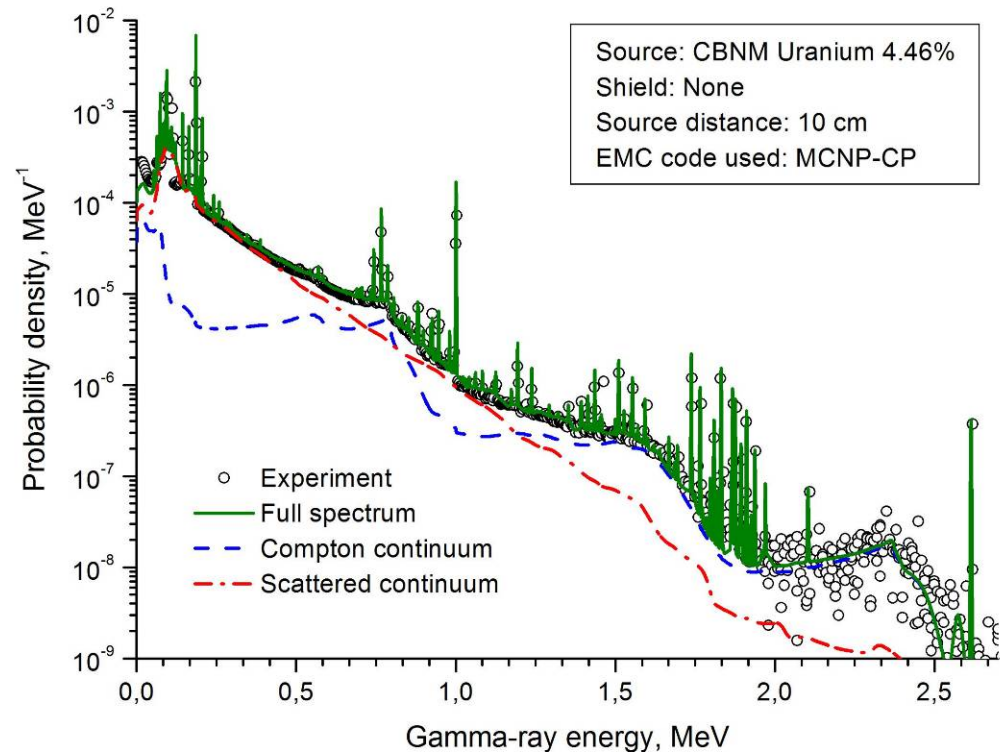
Nuclide	Activity	Nuclide	Activity
^{234}U	14.1 MBq	^{219}Rn	128 Bq
^{238}U	2.02 MBq	^{211}Pb	128 Bq
$^{234\text{m}}\text{Pa}$	2.02 MBq	^{211}Bi	128 Bq
^{234}Pa	3.03 kBq	^{212}Pb	438 Bq
^{234}Th	2.02 MBq	^{212}Bi	438 Bq
^{235}U	607 kBq	^{224}Ra	438 Bq
^{231}Th	607 kBq	^{208}Tl	157 Bq
^{231}Pa	372 kBq	Total	21.4 MBq

Unshielded CBNM-446

Without bremsstrahlung

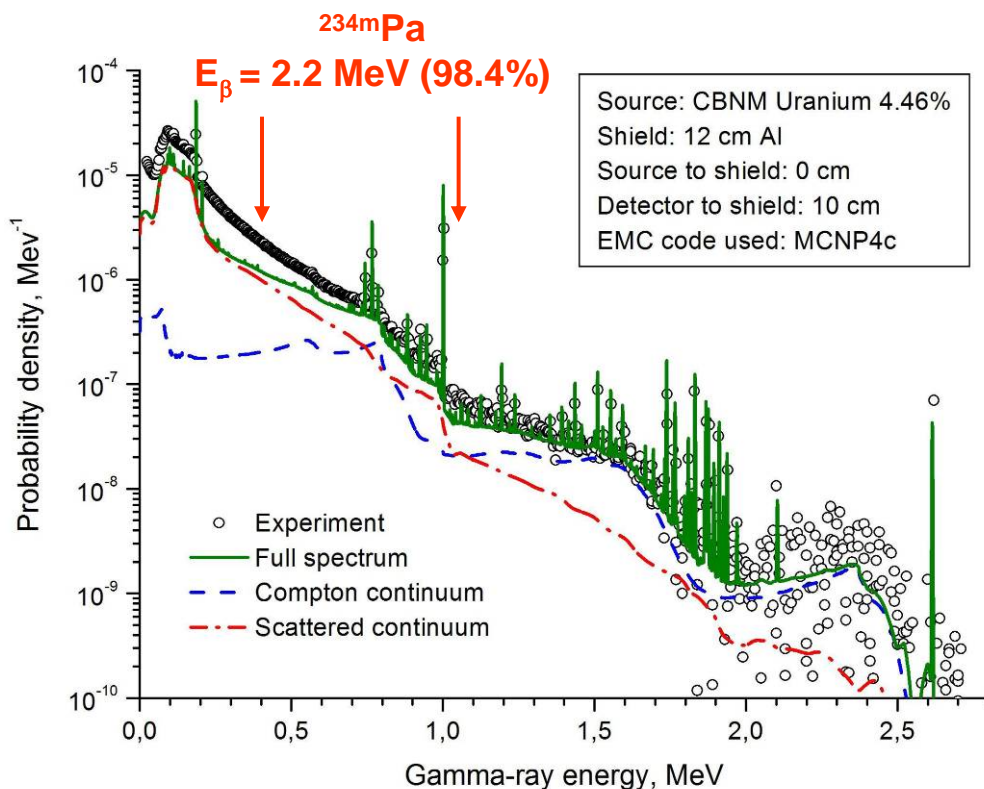


With bremsstrahlung

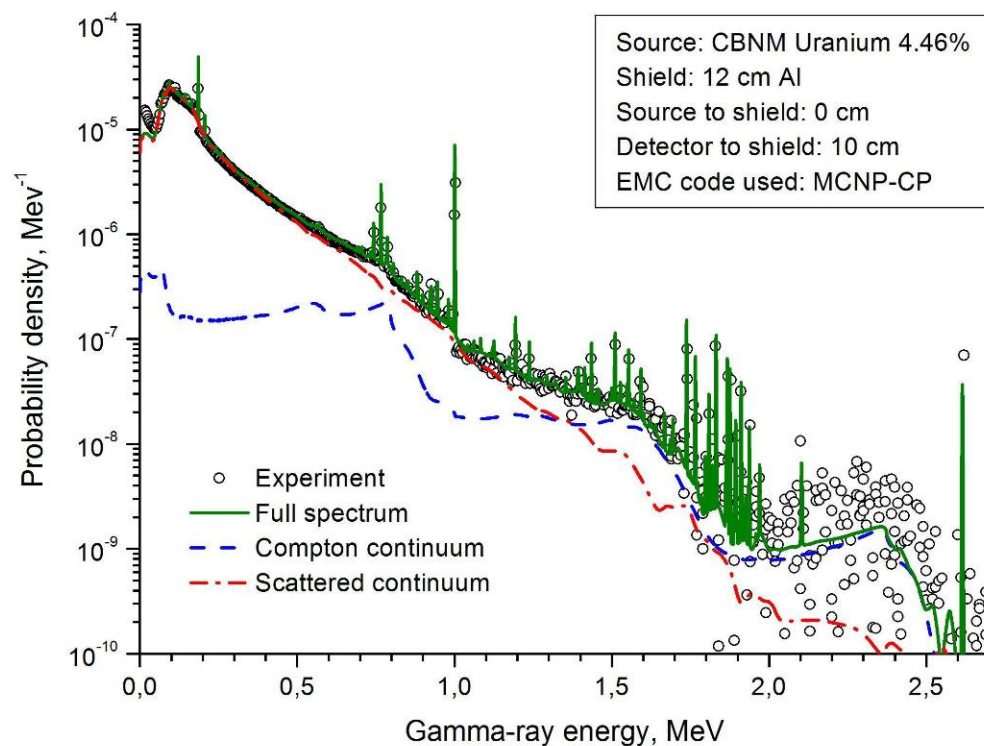


CBNM-446 shielded with 12 cm Al

Without bremsstrahlung



With bremsstrahlung



TACIS: “Supply contract for the mobile laboratory and a transportable analytical instruments and equipment to be used for performing specific on-site actions needed in response to illicit trafficking incidents”

**Technical specifications for
„Gamma radiation search and dose rate measurement instrument”**

Detection sensitivity:

- ≥ 10000 cps/(μ Sv/h) for ^{241}Am
- ≥ 1500 cps/(μ Sv/h) for ^{137}Cs
- ≥ 1000 cps/(μ Sv/h) for ^{60}Co
- ≥ 2500 cps/(μ Sv/h) for natural radiation background



Request from a tenderer:

“We would like to review the requirement for performance. We believe that there is a mistake in the number marked in red. The highest sensitivity should be for ^{60}Co and lowest for ^{241}Am ”.

Step 1: Using Nucleonica's Mass Activity Calculator, evaluate nuclide activities that produce the dose rate of 1 $\mu\text{Sv/h}$ at 1 m distance:

nucleonica ... web driven nuclear science

Applications Data Knowledge My Preferences Print Help New Browser

Version: 2011.04.20 16:33:54

Am241
4.3E2 y

Mass Activity Calculator
95 Americium

Current Chart: Karlsruhe

Element: Am Mass: 241

Quantity: 1 Unit: $\mu\text{Sv/h}$ gamma dose rate

Convert

Convert to:	Quantity
Mass (g)	1.887e-3
Activity (Bq)	2.392e+8
Activity (Ci)	6.466e-3
Number of atoms	4.714e+18
Mole of atoms	7.828e-6
Gamma dose rate ($\mu\text{Sv/h}$)	1.000
Committed Effective Dose Equivalent, E(50)inhalation (μSv)	2.297e+10
Committed Effective Dose Equivalent, E(50)ingestion (μSv)	4.785e+7
Isotopic Power α (Watt)	2.127e-4
Isotopic Power $\alpha+\beta$ (Watt)	2.142e-4
Isotopic Power $\alpha+\beta+\gamma$ (Watt)	2.153e-4

at 100 cm distance (vacuum), Threshold energy (γ & X rays) = 15 keV

240 MBq

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Applications Data Knowledge My Preferences Print Help New Browser

Version: 2011.04.20 16:33:54

Co60
10.47 m 5.27 y

Mass Activity Calculator
27 Cobalt

Current Chart: Karlsruhe

Element: Co Mass: 60

Quantity: 1 Unit: $\mu\text{Sv/h}$ gamma dose rate

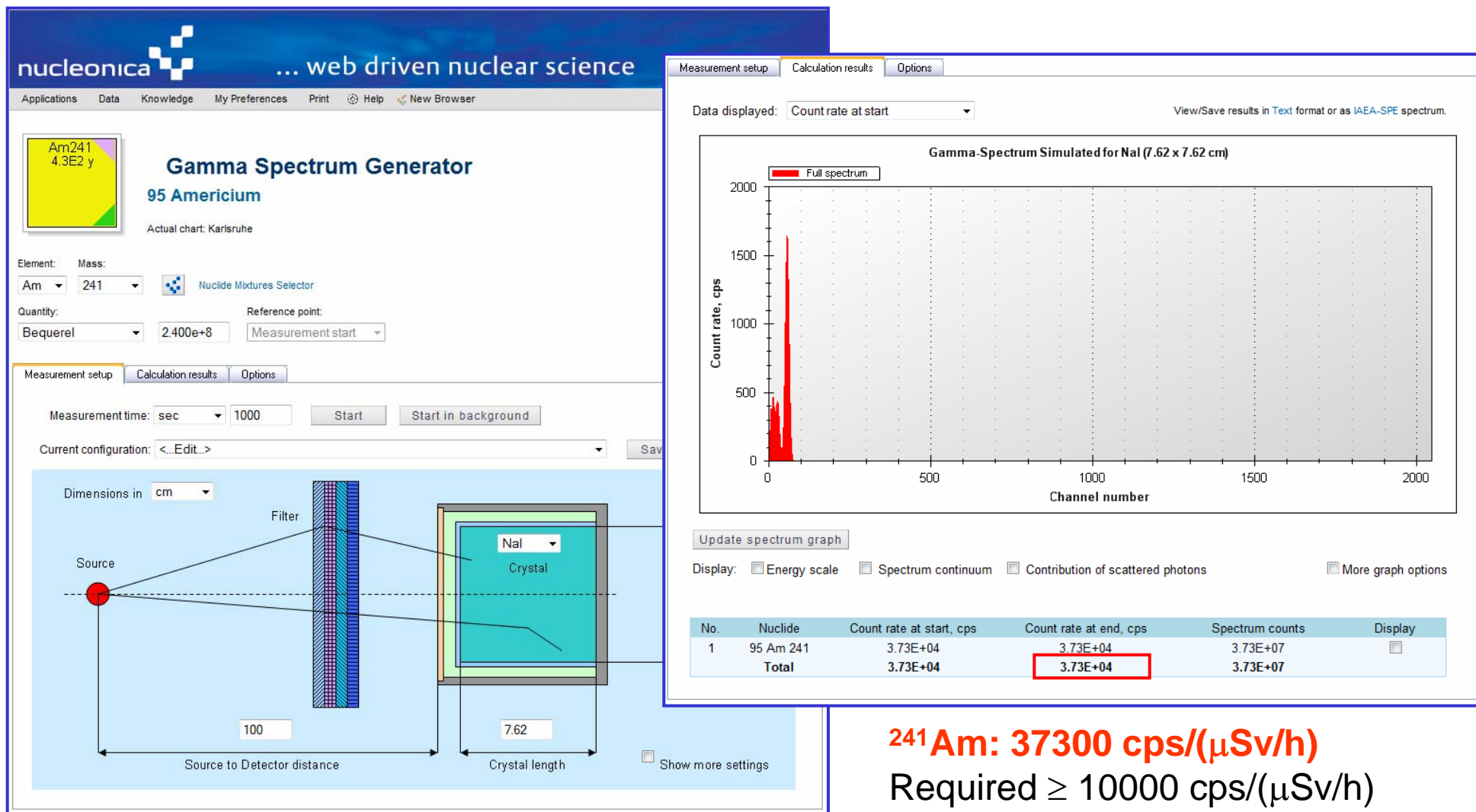
Convert

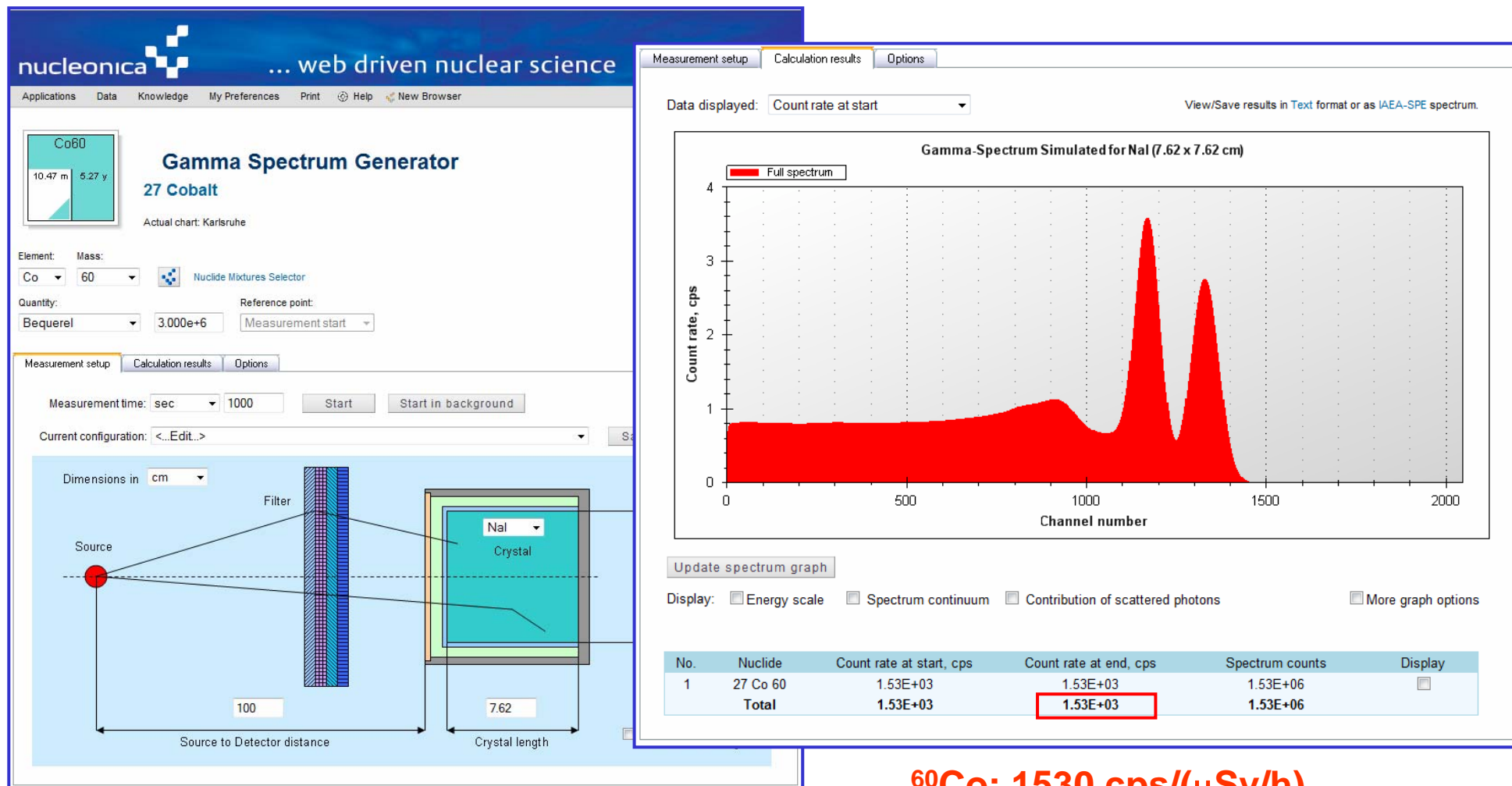
Convert to:	Quantity
Mass (g)	7.087e-8
Activity (Bq)	2.967e+6
Activity (Ci)	8.020e-5
Number of atoms	7.121e+14
Mole of atoms	1.182e-9
Gamma dose rate ($\mu\text{Sv/h}$)	1.000
Committed Effective Dose Equivalent, E(50)inhalation (μSv)	9.199e+4
Committed Effective Dose Equivalent, E(50)ingestion (μSv)	1.009e+4
Isotopic Power α (Watt)	0
Isotopic Power $\alpha+\beta$ (Watt)	4.595e-8
Isotopic Power $\alpha+\beta+\gamma$ (Watt)	1.235e-6

at 100 cm distance (vacuum), Threshold energy (γ & X rays) = 15 keV

3 MBq

Step 2: Using GSG, evaluate the count rates for the 240 MBq ^{241}Am and 3 MBq ^{60}Co sources at 1 m distance. Assume a scintillation detector with a 3'' x 3'' NaI crystal.





^{60}Co : 1530 cps/($\mu\text{Sv/h}$)

Required ≥ 1000 cps/($\mu\text{Sv/h}$)

Thanks !

